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New Research Vessel Ryofu-Maru II and the Cruise Records of old Ryofu-Maru

By

Hideo AKAMATSU

Japan Meteorological Agency

(Received August 29, 1966)

Ryofu-Maru II

1. *The ship*

Ryofu-Maru II (Fig. 1) is a newly-built Meteorological and Oceanographic research vessel and the largest of the fleet of five vessels belonging to the Japan Meteorological Agency. She was designed, built and outfitted for the utmost in efficient Meteorological and Oceanographic service. She is the result not only of several years of actual planning and construction, but also of several decades of experience with the sea and with the seafaring and scientific techniques best suited to a study of the sea.

2. *Ship's characteristics*

She is 80 meters long, 72 meters on the waterline, 12 meters wide and has a draft of 4.35 meters and a gross tonnage is 1,599 tons. She has a cruising speed of 13 knots, the maximum speed 16.5 knots, a range of 15,000 miles. She can accommodate a scientific party of 21 and a permanent crew of 36.

She has a steel hull and one propeller driven by a 3260 H. P. diesel engine. Her rudder is the so-called "Active Rudder" to give her faster turning and maneuverbility, and she has an "Anti-Rolling-Tank", located at the both side of engine-room.

The ship is provided with specially designed scientific work boats. These are also two 57-man wooden life and rescue boats, three 7 meters long wooden work boat, and four 15-man inflatable rubber life rafts of an advanced design, recently approved by the Marine Engineering Institute, the Ministry of Trans-

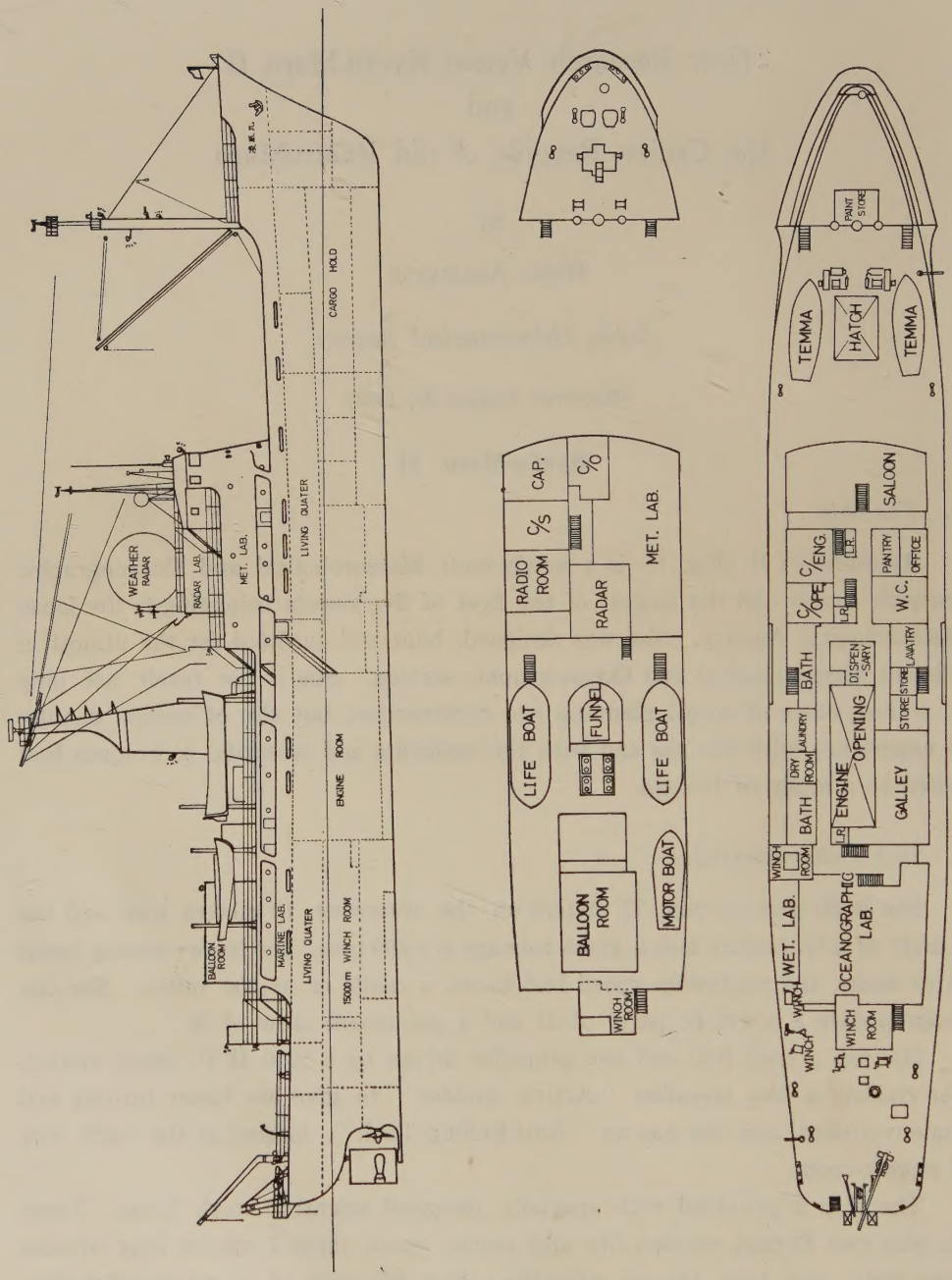

Fig. 1. Ryofu-Maru II.

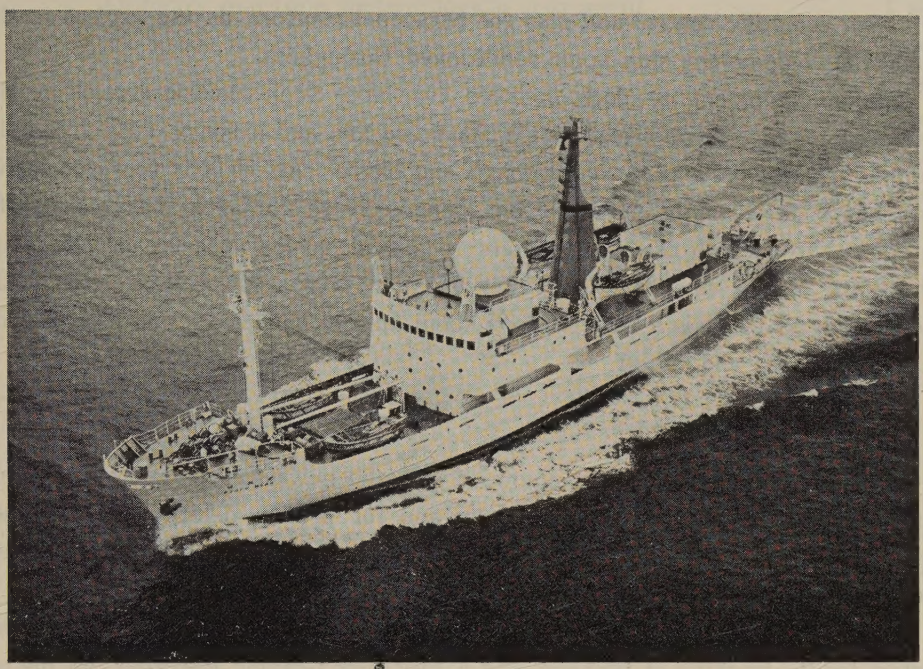

Fig. 2. General arrangement.

portation (Fig. 2).

The vessel was designed by the Marine Division, the Japan Meteorological Agency. She was built by the Ishikawajima-Harima Heavy Industries Company, Tokyo, at a cost of nearly seven hundred million yens.

3. Scientific equipment

Part of the scientific equipment and instruments used on board Ryofu-Maru II during a cruise is provided by the scientific party in order to accommodate the needs and requirements of individual scientists.

The great bulk of the scientific equipment on board, however, is an integral part of the ship's construction and permanently installed. There are two major scientific laboratories on the ship, one located on the boat deck for meteorological observation and the other on the upper deck for oceanographic observation.

There is a fully equipped machine shop to handle at-sea repairs to scientific and ship's equipment. Almost all door sills inside the ship are much lower than is normal for a sea-going ship to provided for safer, more convenient of person-

nel. For scientific control and also for personnel comfort during cruises to the equatorial regions, the ship is air conditioned throughout.

Major equipment on deck includes two large 3-ton electric derrick on the fore-mast, 1-ton electric crane on the starboard aft, and a heavy duty hydraulic bumper frame with a 23-ton capacity on the stern. An electric powered heavy duty winch fitted with enough cable (tapered wire cable) to lower scientific equipment to a depth of 15,000 meters is located in the interior of the ship. There are also 5 smaller winches for use at hydrographic stations at sea. On the boat deck, there is a large balloon room, and in this room, an observation balloon is fill up and let off.

4. Electronics equipment

Ryofu-Maru II is, of course, equipped with the newest electronic instruments for the safe navigation of the ship at sea and for precise determinations of her location during scientific studies. These include radar, loran, depth recorder, radio direction finders, and radio communications gear.

For the use of the scientific party aboard there is a complete weather radar system for the tracking of typhoon, and a Precision Graphic Recorder, an instrument which electronically records depth measurements in the deep ocean. Gyrocompass are located in many part of the ship to give scientific ready reference to the vessel's course. Hydrophone hung to the underwater is used to receive underwater sounds.

The other equipments and characteristics on Ryofu-Maru II are as follows:

(1) Radio Communication Gear

Short wave transmitter: 1 kw	1 set
Short and Medium wave transmitter: 500 W	1 set
Auxiliary Medium wave transmitter: 50 W	1 set
Short wave receiver:	1 set
All wave receiver:	2 sets

(2) Weather Radar with stabilizer 1 set

Range:	400 km
Wave length:	5.7 cm
Peak power:	300 kw

(3) Instruments for Meteorological and Oceanographic Observations

Upper air observation system	1 set
Instrument for research of exchange between air and sea	1 set

Ordinary maritime meteorological instrument 1 set
Facsimile for weather map 1 set
G E K for current measurement 1 set
Instrument for measurement of deep sea current 1 set
Inductively coupled salinometer 2 sets
Photoelectric color meter 1 set
pH meter 1 set
Ordinary serial oceanographical instrument
Nansen reversing water bottle
1.2 *l* type: 24
2.0 *l* type: 22
Reversing thermometer
protected: 150
unprotected: 100
Bathythermograph 5 sets
Piston core-sampler 1 set
Hauling nets for plankton collection various
Selfrecorder of water temperature and salinity of sea surface water 1 set

(4) Main engine: Diesel engine 1 set
Single acting-airless injection, direct reversing gear and trunk-piston type (Supper charger)
Normal out put 2000 H.P.
Maximum out put 3260 H.P.
Propeller: 1 set
Single and 3-bladed propeller
Diameter: 2200 mm
Generator: Main Generator 3 sets
60 c/s, AC. 90 kw, 450 v
Diesel: Trunk-Piston type 3 sets
145 H.P.

(5) Hydrographic Winch: total 6 sets

Deep Sea Winch	15000 m	110 kw (DC)	1 set
Hydro-Winch	8500 m	15 kw (DC)	1 set
	3500 m	5.5 kw (DC)	1 set
	1500 m	3.7 kw (DC)	1 set

B T Winch	1000 m	2.2 kw (DC)	1 set
	250 m	Handling	1 set

(6) Keellaid: November 2, 1965
Launching: May 17, 1966
Delivered: August 16, 1966

She will be on service after September, 1966 and the results of expeditions shall be successively published hereafter.

The Cruise Records of old Ryofu-Maru

The old Ryofu-Maru was built by the Harima Shipyard in August, 1937, and she was scrapped in August, 1966, after her long meteorological and oceanographic service.

Her cruise records sailed during 29 years are as follows (Fig. 3).

(1) Before the World War II (1937—1941)

She worked for the weather observations on the sea of northern part of Kuril Islands, the sea area around Hokkaido, and the south sea of Japan, and, the transportation of cargo for the Kuril Island's weather station, Ogasawara, Iwo-jima and the South-west Islands of Kyushu.

(2) During the World War II (1942—1945)

She was placed under the Japanese Navy control and she worked for the weather observations and report on War's area, and, the transportation of cargo for the weather stations all over the War's area.

(3) After the World War II (1945—1946)

She worked for the transportation of ex-soldiers and the Japanese residents abroad from Chichi-jima, Mariana, Track, Singapore, Borneo and Koro Island (Manchuria).

(4) 1947—1953

She worked for the weather observation at the fixed point, Extra, 39°N, 153°E and Tango, 29°N, 135°E. And she continuously worked for the transportation of cargo and observer for the detached Island's weather stations, Torishima, Amami-Oshima, Minami-Daito-jima and Miyako-jima.

(5) 1954—1966

She worked for the oceanographic observations on the east sea of Honshu, and the transportation of cargo and observer for the detached Island's station, Torishima.

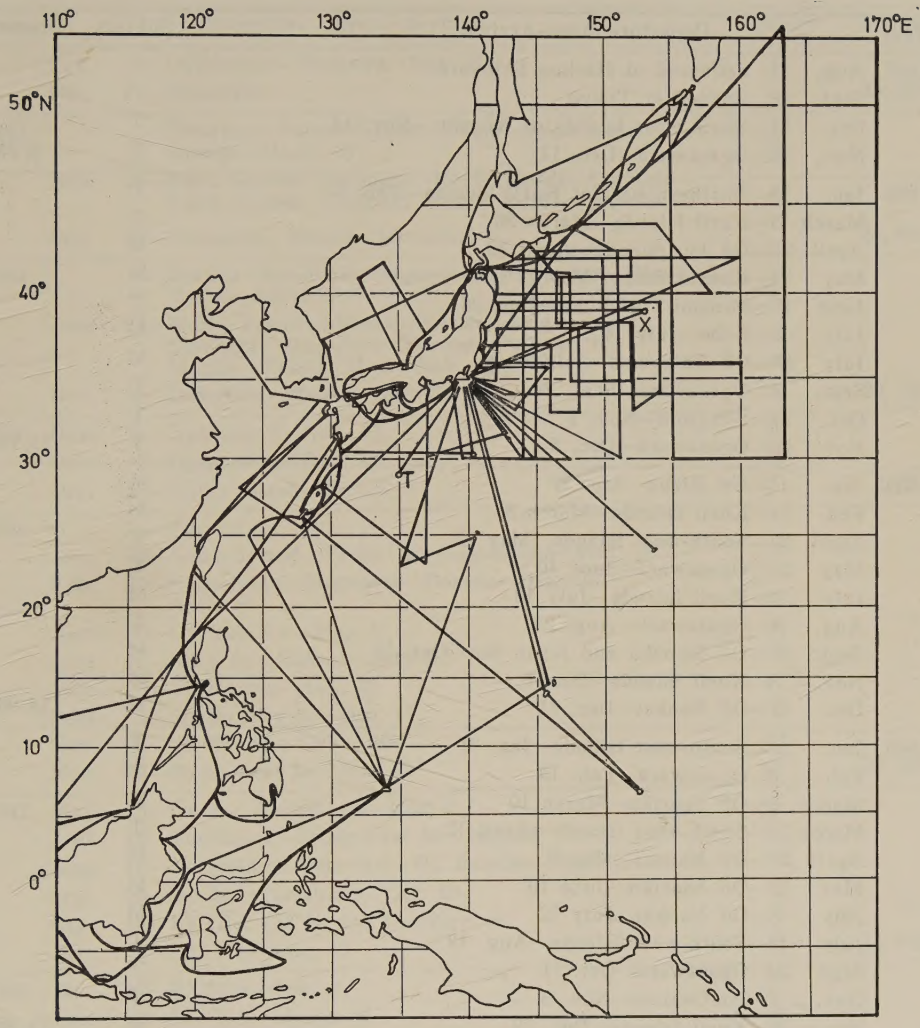

Fig. 3. Track chart of Ryofu-Maru sailed during from 1937 to 1966.

Table 1. The cruise records of old Ryofu-Maru.

Total of crusing distances: 569,479 nautical miles. Number of cruises: 253

Main subject of cruise	abbreviation
(1) Oceanographic observation	O
(2) Meteorological observation	M
(3) Transportation of cargo for the detached Island's weather station	T
(4) Service for ocean weather stations	F
(5) Navigation for docking	D
(6) Navigation for shelter from typhoon	S

Year	Departure–Area–Arrival	Subject	Distance
1937	Aug. 31 delivered at Harima Shipyard		
	Sept. 18 arrived at Tokyo		
	Oct. 31—South-west Islands of Kyushu—Nov. 14	T	
	Nov. 29—Ogasawara—Dec. 11	T	4,240
1938	Jan. 15—Northern part of Kuril Islands—Feb. 9	T	
	March 3—Kuril Islands—March 20	T	
	April 23—Off Izu Islands—April 25	M	
	May 24—Kashimanada—May 27	M	
	June 15—Minami-Torishima—June 26	T	
	July 8—Kobe—July 14	M	
	July 28—Off Tateyama—July 29	M	
	Sept. 3—Ogasawara—Sept. 22	T	
	Oct. 24—Iwo-jima—Nov. 1	T	
	Nov. 25—Ogasawara—Dec. 5	T	15,743
1939	Jan. 14—Off Kishu—Jan. 27	M	
	Feb. 14—Kuril Islands—March 8	M	
	April 27—South-west Islands—May 12	T	
	May 23—Ogasawara—June 10	T	
	July 1—Kuril Islands—July 12	M	
	Aug. 8—Ogasawara—Aug. 23	T	
	Sept. 27—Off Sanriku and Japan Sea—Oct. 16	M	
	Nov. 3—Kuril Islands—Dec. 6	M	
	Dec. 11—Off Nankai—Dec. 21	M	18,969
1940	Jan. 17—South-west Islands—Jan. 31	T	
	Feb. 5—Ogasawara—Feb. 15	T	
	March 2—Off Sanriku—March 10	M	
	March 14—South-west Islands—April 12	T	
	April 24—Off Nankai—May 8	M	
	May 25—Off Sanriku—June 19	M	
	July 3—Off Nankai—July 12	M	
	July 14—South-west Islands—Aug. 12	T	
	Sept. 20—Ogasawara—Oct. 11	T	
	Nov. 2—Izu-Oshima—Nov. 3	T	
	Nov. 25—Kuril Islands—Dec. 19	M	23,882
1941	Jan. 14—South-west Islands—Feb. 8	T	
	Feb. 19—Ogasawara—March 6	T	
	April 10—Ogasawara—April 23	T	
	May 12—Ogasawara—May 22	T	
	June 3—Kuril Islands—June 30	M	
	July 19—South-west Islands—Aug. 13	T	
	Sept. 11—Ogasawara—Sept. 29	T	
	Nov. 10—Kuril Islands—Dec. 16	M	16,725
1942	Jan. 3—Okinawa—Taiwan—Palau—Celebes—Banda Sea—Borneo—Palau—Okinawa—May 27	T	
	June 23—Kuril Islands—Aug. 27	M	

Year		Departure—Area—Arrival	Subject	Distance
	Oct.	5—Ogasawara—Okinawa—Nov. 20	T	
	Dec.	21—Hakodate—		33, 382
1943		—Iwo-jima—Palau—Saipan—Palau—South-west Islands—March 31	T	
	June	26—Kuril Islands—Ominato—Kuril Islands—Ominato—Kuril Islands—Ominato—South Korea—Oct. 28	T	
	Dec.	12—Yokosuka—Manila—Mindanao—		28, 909
1944		—Borneo—Surabaja—Singapore—St. Jacques—Manila—Takao—April 27	T	
	June	20—Moji—Takao—Manila—Borneo—Singapore—Surabaja—Singapore—Borneo—Palawan Is.—Manila—Takao—Moji—Nov. 16	T	
	Nov.	25—Hakodate—Maoka—Dec. 22	T	20, 958
1945	Nov.	21—Ogasawara—Nov. 27	T	
	Dec.	3—Ogasawara—Dec. 27	T	
	Dec.	28—Gaum Island—Tinian—		4, 127
1946		—Jan. 12		
	Jan.	20—Gaum Island—Truck Is.—Kagoshima—Feb. 17	T	
	Feb.	25—Kagoshima—Singapore—Borneo—Daichiku—April 10	T	
	April	16—Off Sanriku—May 3	M	
	June	28—Koro Is.—Hakata—July 20	T	
	July	26—Torishima—Aug. 15	T	
	Sept.	11—South-west Is.—Oct. 12	T	
	Nov.	8—Off Sanriku—Nov. 20	M	
	Nov.	29—South-west Is.—Dec. 25	T	27, 462
1947	May	25—Izu Is.—Torishima—June 2	T	
	June	18—Torishima—South-west Is.—July 18	T	
	Aug.	10—Torishima—Hakodate—Off Sanriku—Sept. 3	M	
	Sept.	30—Izu Is.—Torishima—Oct. 10	T	
	Oct.	16—EXTRA (39°N, 153°E)—Nov. 8	F	
	Dec.	1—EXTRA—Dec. 18	F	11, 836
1948	Jan.	17—EXTRA—Feb. 8	F	
	Feb.	25—EXTRA—March 20	F	
	May	14—EXTRA—June 5	F	
	July	14—EXTTA—Aug. 5	F	
	Aug.	21—EXTRA—Sept. 14	F	
	Oct.	8—EXTRA—Nov. 4	F	
	Nov.	—Torishima—South-west Is.—Dec. 27	T	15, 978
1949	Jan.	16—EXTRA—Feb. 6	F	
	March	15—EXTRA—April 7	F	
	June	19—EXTRA—July 14	F	
	July	27—Torishima—South-west Is.—Aug. 26	T	
	Sept.	12—EXTRA—Oct. 6	F	
	Nov.	10—Torishima—Nov. 19	T	

Year	Departure—Area—Arrival	Subject	Distance
	Dec. 6—South-west Is.—		13, 560
1950	—Jan. 26	T	
	Feb. 8—Torishima—Feb. 17	T	
	April 1—EXTRA—April 26	F	
	May 2—Torishima—May 11	T	
	June 27—EXTRA—July 23	F	
	Aug. 8—Torishima—Aug. 18	T	
	Sept. 6—TANGO (29°N, 135°E)—Sept. 28	F	
	Oct. 10—EXTRA—Nov. 3	F	
	Nov. 15—TANG—Dec. 8	F	
	Dec. 21—EXTRA—		16, 012
1951	—Jan. 14	F	
	Feb. 5—EXTRA—Feb. 28	F	
	March 26—TANGO—April 20	F	
	May 13—EXTRA—June 7	F	
	July 2—TANGO—July 28	F	
	Aug. 4—Torishima—Aug. 16	T	
	Oct. 10—EXTRA—Nov. 6	F	
	Nov. 18—TANGO—Dec. 10	F	14, 292
1952	Jan. 5—EXTRA—Jan. 27	F	
	Feb. 21—TANGO—March 14	F	
	April 2—EXTRA—April 26	F	
	May 8—Torishima—May 17	T	
	July 7—TANGO—July 30	F	
	Aug. 8—Torishima—Aug. 17	T	
	Sept. 3—EXTRA—Sept. 28	F	
	Oct. 26—TANGO—Nov. 19	F	
	Dec. 7—EXTRA—Dec. 29	F	15, 547
1953	Jan. 10—Torishima—Jan. 20	T	
	Jan. 29—TANGO—Feb. 22	F	
	March 16—EXTRA—April 8	F	
	May 3—TANGO—May 28	F	
	July 15—Torishima—July 23	T	
	Aug. 7—TANGO—Aug. 31	F	
	Oct. 1—Torishima—Oct. 12	T	
	Nov. 4—EXTRA—Nov. 30	F	
	Dec. 18—Torishima Dec. 23	T	13, 625
1954	Jan. 12—Torishima—Jan. 20	T	
	Feb. 25—Off Sanriku—March 26	O	
	April 28—Torishima—May	T	
	May 17—Off Sanriku—June 18	O	
	July 28—Torishima—Aug. 6	T	
	Aug. 16—Off Sanriku—Sept. 21	O	
	Sept. 23—Marcus Is.—Oct. 3	T	

Year	Departure—Area—Arrival		Subject	Distance
	Oct. 8—Torishima—Oct. 17		T	
	Oct. 22—Torishima—Oct. 31		T	
	Nov. 10—Off Sanriku—Dec. 4		O	20,694
1955	Jan. 18—Torishima—Jan. 30		T	
	Feb. 10—Off Sanriku—March 14		O	
	April 16—Torishima—April 23		T	
	May 6—Off Sanriku—June 2		O	
	June 21—Torishima—June 27		T	
	July 15—Torishima—Aug. 1		T	
	Aug. 12—Off Sanriku—Sept. 24	NORPAC	O	
	Oct. 13—Torishima—Oct. 24		T	
	Nov. 11—Off Sanriku—Nov. 28		O	21,306
1956	Jan. 17—Torishima—Feb. 2		T	
	Feb. 14—Off Sanriku—March 9		O	
	April 14—Torishima—April 23		T	
	May 10—Off Sanriku—Off Kisyu—June 7	IGY	O	
	June 18—Off Sanriku—June 30		O	
	July 10—Torishima—July 19		T	
	Aug. 1—Off Sanriku—Aug. 27		O	
	Sept. 17—Off Sanriku—Oct. 6		O	
	Oct. 12—Torishima—Oct. 25		T	
	Nov. 6—Off Sanriku—Nov. 21		O	22,406
1957	Jan. 10—Torishima—Jan. 17		T	
	Feb. 14—Off Sanriku—March 14		O	
	March 18—Off Tateyama—March 19		O	
	April 10—Torishima—April 19		T	
	April 26—Off Boso—April 28		O	
	May 6—Off Sanriku—May 21		O	
	June 7—Off Sanriku—July 10	IGY	O	
	July 19—Torishima—July 28		T	
	Aug. 6—Off Boso—Aug. 8		O	
	Aug. 19—Off Sanriku—Sept. 5		O	
	Sept. 14—Off Sanriku—Oct. 7	IGY	O	
	Oct. 17—Torishima—Oct. 26		T	
	Nov. 5—Off Sanriku—Nov. 20		O	
	Nov. 26—Off Haneda—Nov. 26		S	26,300
1958	Jan. 10—Torishima—Jan. 17		T	
	Feb. 17—Off Sanriku—March 14		O	
	April 11—Torishima—April 20		T	
	May 6—Off Sanriku—May 29		O	
	July 3—Torishima—July 11		T	
	July 25—Off Sanriku—Sept. 16	IGY	O	
	Oct. 8—Torishima—Oct. 16		T	
	Nov. 5—Off Sanriku—Nov. 30		O	22,256
1959	Jan. 10—Torishima—Jan. 18		T	

Year	Departure—Area—Arrival		Subject	Distance
	Jan. 26—Off Sanriku—March 24		O	
	March 30—Off Tateyama—March 31		O	
	April 14—Torishima—April 27		T	
	May 7—Off Sanriku—June 10		O	
	June 23—Off Sanriku—June 29	JEDS-1	O	
	July 10—Torishima—July 22		T	
	Aug. 1—Off Sanriku—Aug. 25		O	
	Sept. 5—Off Sanriku—Sept. 30	JEDS-2	O	
	Oct. 10—Torishima—Oct. 22		T	
	Oct. 11—Off Sanriku—Nov. 20		O	
	Dec. 25—Off Haneda—Dec. 25		S	23,018
1960	Jan. 12—Torishima—Jan. 18		T	
	Feb. 16—Off Sanriku—March 19		O	
	April 8—Torishima—April 16		T	
	April 18—Torishima—April 29		T	
	May 12—Hachijo-jima—Suruga Bay—June 20	JEDS-3		
	July 8—Torishima—July 17		T	
	Aug. 10—Off Sanriku—Sept. 17		O	
	Oct. 5—Torishima—Oct. 13		T	
	Oct. 25—Honshu Nankai—East China Sea—Nov. 22		O	21,966
1961	Jan. 12—Torishima—Jan. 18		T	
	Feb. 10—Off Sanriku—March 18		O	
	April 11—Torishima—April 21		T	
	May 10—Off Sanriku—May 24	JEDS-4	O	
	June 5—Off Sanriku—June 30	JEDS-4	O	
	July 12—Torishima—July 20		T	
	Aug. 1—Off Sanriku—Sept. 12		O	
	Sept. 15—Off Boso—Sept. 17		O	
	Oct. 6—Hachijo-jima—Oct. 10		O	
	Oct. 11—Torishima—Oct. 18		T	
	Oct. 30—Off Honshu—Nov. 29		O	
	Dec. 3—Shimizu—			20,112
1962	—Jan. 6		D	
	Jan. 11—Torishima—Jan. 18		T	
	Feb. 5—Off Sanriku—March 16		O	
	March 19—Shimizu—March 30		D	
	April 11—Torishima—April 22		T	
	May 8—Off Sanriku—May 31	JEDS-5	O	
	June 8—Off Sanriku—June 30	JEDS-5	O	
	July 12—Torishima—July 23		T	
	Aug. 3—Off Sanriku—Aug. 24		O	
	Aug. 27—Miyake-jima—Sept. 2		O	
	Sept. 6—Off Sanriku—Sept. 29		O	
	Oct. 10—Torishima—Oct. 22		T	
	Nov. 8—Off Honshu Nankai—Nov. 22		O	

Year	Departure—Area—Arrival		Subject	Distance
	Dec. 27—Off Haneda—Dec. 27			23, 567
1963	Jan. 11—Torishima—Jan. 27		T	
	Feb. 5—Torishima—Feb. 10		T	
	Feb. 18—Off Sanriku—March 20		O	
	April 12—Torishima—April 22		T	
	May 7—Off Sanriku—June 22	JEDS-6	O	
	July 5—Off Sanriku—July 25	JEDS-6	O	
	Aug. 9—Torishima—Aug. 21		T	
	Aug. 26—Torishima—Sept. 5		T	
	Sept. 16—Off Sanriku—Oct. 10		O	
	Oct. 23—Japan Sea—Nov. 18		M	
	Nov. 28—Torishima—Dec. 7		T	
	Dec. 10—Shimizu—			24, 750
1964	—Jan. 16		D	
	Jan. 28—Off Sanriku—Feb. 26		O	
	March 5—Torishima—March 14		T	
	April 20—Off Sanriku—May 29	JEDS-8	O	
	June 10—Torishima—June 21		T	
	June 27—Torishima—July 4		T	
	July 18—Off Sanriku—July 31		O	
	Aug. 3—Off Sanriku—Sept. 7		O	
	Sept. 16—Torishima—Sept. 24		T	
	Sept. 29—Torishima—Oct. 3		T	
	Oct. 14—Off Honshu Nankai—Oct. 31		O	
	Nov. 4—Shimizu—Dec. 4		D	
	Dec. 9—Torishima—Dec. 17		T	20, 476
1965	Jan. 25—Off Sanriku—Feb. 26		O	
	March 5—Torishima—March 15		T	
	April 22—Off Honshu Nankai—May 26	JEDS-10	O	
	June 8—Torishima—June 16		T	
	June 25—Off Sanriku—Aug. 9	CSK	O	
	Aug. 21—Off Haneda—Aug. 24		S	
	Sept. 12—Torishima—Sept. 25		T	
	Oct. 1—Torishima—Oct. 10		T	
	Nov. 14—Torishima—Nov. 18		T	
	Dec. 10—Torishima—Dec. 19		T	17, 968
1966	Jan. 8—Japan Sea—Jan. 26		M	
	Feb. 3—Off Sanriku—Feb. 12	CSK	O	
	Feb. 22—Off Sanriku—March 11		O	
	March 15—Off Izu Is.—March 19		O	
	March 22—Torishima—March 31		T	
	April 20—Hachijo-jima—May 4		O	
	May 11—34°30′N, 141°00′E—May 16		M	
	May 19—34°30′N, 141°00′E—May 26		M	

Year	Departure—Area—Arrival	Subject	Distance
June	6—33°30′N, 138°00′E—June 11	M	
June	21—Torishima—June 29	T	9,413

Reference

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The General Account of the Plankton Survey on the Sixth (1963), Eighth (1964) and Tenth Cruise (1965) of the Japanese Expedition of Deep-Sea*

By

Yutaka KAWARADA

Japan Meteorological Agency

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1. *Introduction*

Researches on mid-water plankton by the R/V Ryofu Maru of the Japan Meteorological Agency have been carried out on her cruises of the Japanese Expedition of Deep-Sea (JEDS) in the waters surrounding Japan, since 1959. Outlines of their results obtained on the Second to the Fifth Cruise of JEDS have already been reported (SUYEHIRO *et al.*, 1960; MARUMO, 1960, 1961; MATSUE *et al.*, 1961; MATSUE *et al.*, 1962; MARUMO, 1962; MATSUE *et al.*, 1963; MARUMO and KAWARADA, 1963), and dealing with the materials collected on these cruises, taxonomical and ecological studies on deep water plankton have also been reported (KOMAKI, 1960; IMAJIMA, 1961; HARADA, 1962; KITOU, 1963; NAGATA, 1963; MARUMO, 1963; OKUTANI, 1964; KITOU, 1965).

After that, the cruises of JEDS have been carried out continuously in the sea areas adjacent to the Japan Trench, Kurile Trench and Izu-Ogasawara Submarine Ridge. In addition to the previous cruises, the approximate location of the sampling positions of the Sixth, Eighth and Tenth Cruise of JEDS is shown in Fig. 1, which is drawn on the basis of the data and figures described in the preliminary reports of JEDS (TERADA and FUTI, 1960; MASUZAWA, 1961, 1962; YASUI, 1963; AKAMATSU, 1964; KATSUURA *et al.*, 1964; AKAMATSU, 1965; AKAMATSU *et al.*, 1965).

In this paper, a general account on sampling methods and the results of collections will given. Further detailed studies on collected animal groups will

* JEDS Contribution No. 78

be done by specialists in each field taxonomically and ecologically in near future.

2. *JEDS-6*

The Japanese Expedition of Deep-Sea, the Sixth Cruise (JEDS-6), was carried out from May to June of 1963, in the sea area adjacent to the saddle part between the northern part of the Japan Trench and the south-western part of the Kurile Trench.

Collections of mid-water plankton were made at St. G207 (Fig. 1) in June with a 130-cm conical net, which was the same type as had been used on the Second and the Fourth Cruise of JEDS (Suyehiro *et al.*, 1960; Matsue *et al.*, 1962). The mouth diameter of the net is 130 cm, and the total side length is 500 cm, being made of coarse nylon cloth, 2 mm×2 mm mesh apertures, in the upper 400-cm part and of nylon bolting cloth GG54, 0.33 mm×0.33 mm mesh apertures, in the lower 100-cm part. The net was hauled vertically from the depths of 1000 m and 3000 m to the surface, respectively.

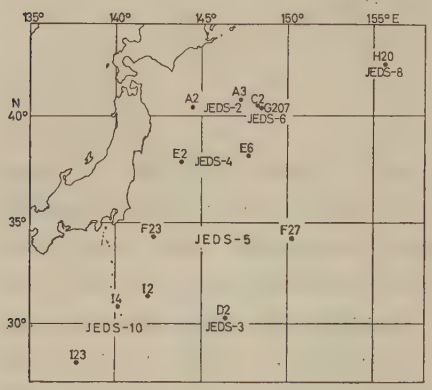

Fig. 1. Approximate location of sampling positions on the cruises of JEDS of R/V Ryofu Maru.

The counting of specimens was made for each taxonomical plankton group and the result is given in Table 1. Detailed studies on some copepods have been reported (Kitou, 1965).

In addition to the 130-cm conical net, a 130-cm closing net with bolting cloth GG54 was used on this cruise. It has the same construction as the 130-cm closing net which has been used on the Fifth Cruise of JEDS (Matsue *et al.*, 1963), but the netting of these nets is different from each other; the former is made of bolting cloth GG54, 0.33 mm×0.33 mm mesh apertures, only, and the latter is consisted of coarse nylon cloth, 3 mm×3 mm mesh apertures, at the upper 540-cm part and bolting cloth GG54 at the lower 140-cm part. Preventing the contamination by small animals at the sea surface through more or less wide mesh apertures as 3 mm×3 mm, bolting cloth GG54 is substituted for coarse nylon cloth. Sampling of plankton with this net was made in the vertical ranges

Table 1. Individual numbers of each group (JEDS–6).

Station No.		G207	
Location	Lat. N	40–24	40–23
	Long. E	148–28	148–26
		↓	↓
	Lat. N	40–25	40–24
	Long. E	148–32	148–28
Date		6–17	6–16
			–17
Time		0255	2312
		0400	0223
Hauled Distance (m)		0–1000	0–3000
Radiolaria		+	+
Coelenterata		128	264
Chaetognatha	(w)	2030	1563
	(c)	10	48
Nemertini		1	1
Polychaeta		40	27
Crustacea	Copepoda (l)	4920	6481
	Copepoda (s)	2156	1264
	Cladocera	–	64
	Ostracoda	140	400
	Euphausiacea	116	159
	Isopoda	5	52
	Amphipoda	109	677
	Decapoda	25	39
Mesogastropoda		1	–
Pteropoda		3	31
Cephalopoda		2	2
Thaliacea		253	1418
Pisces		37	56
Egg		–	8

(w), (c): Intestine is stained with orange oil grobules in (c) and not stained in (w).
(l): larger than 1.5 mm in length.
(s): smaller than 1.5 mm in length.

of the depth of 500 m to the surface and 2000 m to 1000 m, respectively, at St. G204 (40°50′N, 144°45′E), but the amounts of plankton samples were very small. When the net was lowered down to the depth of 4000 m to obtain samples from the depths of 4000 m to 3000 m, the cloth was torn up. Then, the new one was

lowered down to the depth of 6000 m to be closed at the depth of 3000 m, but the cloth was also torn up. Judging from the successful operation of the 130-cm closing net on the Fifth Cruise of JEDS, bolting cloth GG54 may be too fine to strain much volume of water. So removal of coarse nylon cloth from such a large plankton net is not suitable to collect the deep water plankton.

3. *JEDS-8*

The Japanese Expedition of Deep-Sea, the Eighth Cruise (JEDS-8), was

Table 2. Individual numbers of each group (JEDS-8).

Station No.		H20			
Location	Lat. N	42–20	42–21	42–24	42–22
	Long. E	155–30	155–32	155–40	155–35
		↓	↓	↓	↓
	Lat. N	42–19	42–20	42–22	42–21
	Long. E	155–31	155–31	155–35	155–34
Date		5–20	5–20	5–19	5–19
					–20
Time		0350	0127	1345	2112
		0440	0257	2032	0053
Hauled Distance (m)		0–700	500–1000	1000–2000	2000–3000
Radiolaria		+	+	+	–
Coelenterata		503	172	54	67
Chaetognatha	(w)	1281	62	262	102
	(c)	–	–	8	1
Polychaeta		56	10	17	–
Crustacea	Copepoda (l)	3940	450	1400	452
	Copepoda (s)	2288	832	464	224
	Ostracoda	432	1	21	6
	Mysidacea	–	–	1	–
	Euphausiacea	25	34	–	1
	Isopoda	4	–	3	–
	Amphipoda	15	7	2	1
Pteropoda		16	–	–	–
Thaliacea		40	5	–	–
Pisces		7	2	7	–
Pisces scale		496	32	528	4
Egg		3	–	–	–

(w), (c): Intestine is stained with orange oil grobules in (c) and not stained in (w).
(l): larger than 1.5 mm in length.
(s): smaller than 1.5 mm in length.

carried out from April to May of 1964, in the sea area southwest of Hokkaido, which was nearly the same area as that of JEDS-6.

Collections of mid-water plankton were made at St. H20 (Fig. 1) with a 130-cm closing net which was the same type as had been used on the Fifth Cruise of JEDS (MATSUE *et al.*, 1963). The net was hauled vertically from the depth of 700 m to the surface, 500 m to 1000 m, 1000 m to 2000 m and 2000 m to 3000 m, respectively.

The counting of specimens was made for each taxonomical plankton group and the result is given in Table 2.

4. JEDS-10

The Japanese Expedition of Deep-Sea, the Tenth Cruise (JEDS-10), was carried out from April to May of 1965, at the neighborhood of the northern part of the Izu-Ogasawara Submarine Ridge.

In order to observe the differences of the planktological properties between the eastern side and the western side of the Ridge, collections of mid-water plankton were made at three stations. One of them was situated over the Ridge (St. I 4) and others were on both sides of the Ridge (Sts. I 2, I 23) (Fig. 1). At Sts. I 2 and I 23, a 130-cm closing net which was the same type as had been used on the Fifth and Eighth Cruise of JEDS, was hauled vertically from the depth of 500 m to the surface, 1000 m to 500 m, 2000 m to 1000 m and 3000 m to 2000 m, respectively. At St. I 4, however, as the water depth was 1818 m, the vertical tow of the net was carried out from the depth of 500 m to the surface, 1000 m to 500 m and 1800 m to 1000 m.

The counting of specimens was made for each taxonomical plankton group and the result is given in Table 3. Being necessary to require further examination, it seems that there is no differences of essential characters of the plankton group between the western part and eastern part of the Ridge.

5. General account of the plankton survey of JEDS

Among mid-water animal groups collected on the cruises of JEDS from the Second to the Tenth, copepods are most predominant in number and chaetognaths come to the next. The total individual numbers of copepods and chaetognaths in the water column from the surface to the depth of 3000 m at each station are shown in Figs. 2 and 3, respectively. At Sts. A3, E2 and E6, samples were collected from the depth of 3000 m to the surface by a single vertical haul of a

Table 3. Individual numbers of each group (JEDS-10).

Station No.	I2				I4			I23			
Location Lat. N	31-21	31-22	31-23	31-25	30-54	30-54	30-54	27-58	27-59	28-00	28-01
Long E	142-00	141-59	141-57	141-54	140-14	140-14	140-15	137-52	137-52	137-52	137-53
	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Lat. N.	31-22	31-23	31-24	31-27	30-54	30-54	30-54	27-59	28-00	28-01	28-01
Long. E	141-59	141-58	141-55	141-50	140-14	140-15	140-15	137-52	137-52	137-52	137-56
Date	4-26	4-26	4-26	4-26	4-29	4-28	4-28 -29	5-18	5-18	5-18	5-18
Time	1146	1310	1444	1655	0029	2134	2245	0840	0928	1045	1245
	1227	1412	1635	1925	0100	2228	0014	0910	1030	1230	1518
Hauled Distance (m)	0-500	500-1000	1000-2000	2000-3000	0-500	500-1000	1000-1800	0-500	500-1000	1000-2000	2000-3000
Radiolaria	+	+	+	+	+	+	+	—	+	—	—
Coelenterata	40	151	165	40	28	101	152	110	145	23	9
Chaetognatha (w)	507	222	139	19	101	171	172	497	38	28	20
(c)	—	1	—	—	—	1	—	—	—	—	—
Nemertini	—	1	—	—	—	—	—	—	—	—	—
Polychaeta	8	—	9	—	3	32	24	8	1	—	—
Crustacea Copepoda (l)	470	289	211	43	314	204	246	788	259	128	91
Crustacea Copepoda (s)	912	247	512	200	1616	984	1600	2608	400	296	364
Crustacea Ostracoda	96	8	32	8	27	98	104	176	29	36	4
Crustacea Euphausiacea	69	70	11	—	3	66	10	8	51	3	1
Crustacea Isopoda	—	—	3	—	—	—	8	—	—	—	—
Crustacea Amphipoda	36	12	17	6	31	16	48	14	4	1	—
Crustacea Decapoda	5	—	6	—	—	—	—	1	—	—	1
Mesogastropoda	—	2	—	—	—	—	—	2	—	—	1
Pteropoda	81	33	10	8	34	80	144	18	1	1	—
Thaliacea	479	2912	536	228	14	19	784	114	4	30	4
Pisces	13	11	2	—	3	15	24	—	8	—	1
Egg	8	—	—	—	—	—	—	1	—	1	—

(w), (c): Intestine is stained with orange oil grobules in (c) and not stained in (w).
(l): larger than 1.5 mm in length.
(s): smaller than 1.5 mm in length.

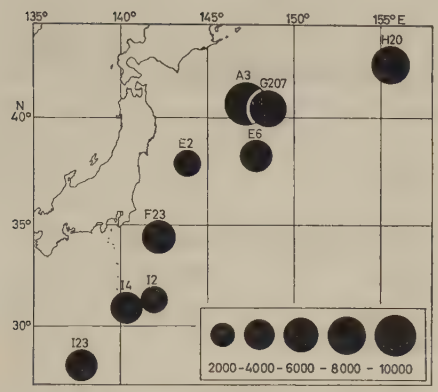

Fig. 2. Total individual numbers of copepods in the vertical zones from the surface to the depth of 3000 m.

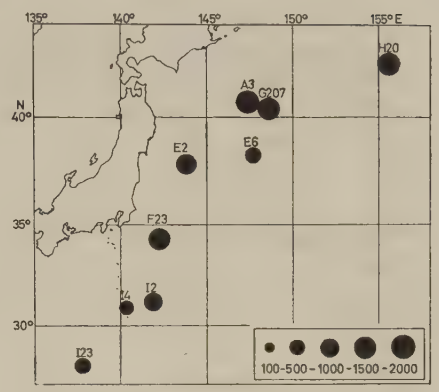

Fig. 3. Total individual number of chaetognaths in the vertical zones from the surface to the depth of 3000 m.

130-cm conical net, while at Sts. F23, F27, H20, I 2, I 4 and I 23, as samples were collected by repeated hauls from the four vertical zones (0 m-500 m, 500 m-1000 m, 1000 m-2000 m, 2000 m-3000 m) with a 130-cm closing net, the amounts of copepods as well as chaetognaths are expressed as total counts of four zones.

Copepods are much in number in the northern sea area from lat. 40°N, being more than 7000 individuals per 4000 cubic meters of sea water, and they decrease to less than 5000 individuals in the sea area far south of Japan. As copepods include various sizes in length, they are divided in two groups, namely large specimens, being more than 1.5 mm in length and small specimens, less than 1.5 mm. The counts of the large specimens are much in abundance in the northern sea area from lat. 40°N. On the contrary, the small specimens are predominant in the southern sea area from lat. 40°N.

Chaetognaths hold more or less large number, being more than 1000 individuals per 4000 cubic meters of sea water, from the sea areas of the northern part of lat. 40°N to the vicinity of 34°N, 143°E along the east coast of Japan. However, in the sea area far south of Japan, which is situated in the oceanic side of the Kuroshio, the population density of chaetognaths is small in quantity (400 individuals). These properties of distributional patterns of chaetognaths resemble those of copepods.

The vertical distributions of the total number of copepods, the water temperatures and the chlorinities at the six stations are shown in Fig. 4. The copepod maximum is observed in the vertical range of water column from the surface to the depth of 500 m at each station, and below this layer, copepods

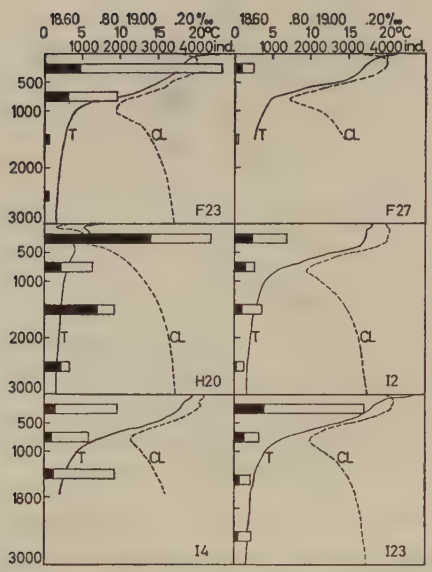

Fig. 4. Vertical distribution of individual numbers of copepods (black: large specimens more than 1.5 mm in length, white: small specimens less than 1.5 mm), water temperature (T) and chlorinity (CL) at each station.

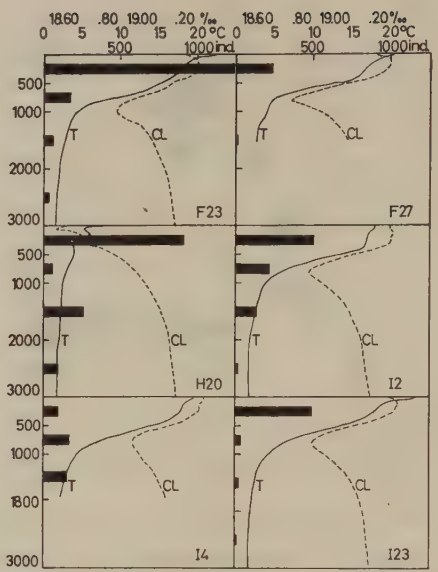

Fig. 5. Vertical distribution of individual numbers of chaetognaths, water temperature (T) and chlorinity (CL) at each station.

decrease suddenly, except for St. I 4, where they hold nearly same density from the surface to the sea-bottom (depth 1818 m). At St. H20, the population density of copepods is fairly abundant in the water column from the depth of 500 m to 2000 m. Such distributions of copepods may depend upon the Oyashio waters, which is recognized by the low water temperature and low chlorinity in the surface layer. The large specimens of copepods more than 1.5 mm in length at St. H20, are abundantly distributed through the vertical range from the surface to the depth of 3000 m. They are more abundant than the small specimens of copepods with lengths of less than 1.5 mm, but at other stations, the relationship becomes reverse. At St. H20, we obliged to spend much time in collecting the samples from the depth of 2000 m to 1000 m as shown in Table 2, and the population density of copepods as well as chaetognaths is fairly large.

The vertical distributions of chaetognaths, the water temperature and the chlorinities at the six stations are shown in Fig. 5. The abundance of chaetognaths in the vertical range from the surface to the depth of 500 m, is similar to that of copepods, but at St. I 4, the amounts of chaetognaths increase with in-

creasing depth. Below the depth of 500 m the populations of chaetognaths decrease suddenly, as in the case of copepods.

The relationship between the population density of the animal groups and the water temperatures as well as chlorinities, is obscure.

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Automatic Opening-and-Closing Multiple Net

By

Yutaka KAWARADA and Hideo AKAMATSU

Japan Meteorological Agency

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1. Introduction

The vertical distribution of plankton through a large vertical range is not yet sufficiently known, owing to the operational difficulties in sampling uncontaminated materials from desired zones of the water separately. Repeated hauls from several depths with an ordinary closing net, such as Nansen net, Juday net, etc., are laborious and time-consuming works. Several devices on plankton sampler collecting samples from different zones by a single haul have been published (MOTODA, 1953; BÉ *et. al.*, 1959; BÉ, 1962; MOTODA, 1963) and some of them can be practically used.

An automatic opening and closing multiple net (Fig. 1) described here was devised for sampling plankton from each 250 m zone through the depths from 1000 m to the surface by a single vertical haul separately by means of automatic release operated by a propeller system.

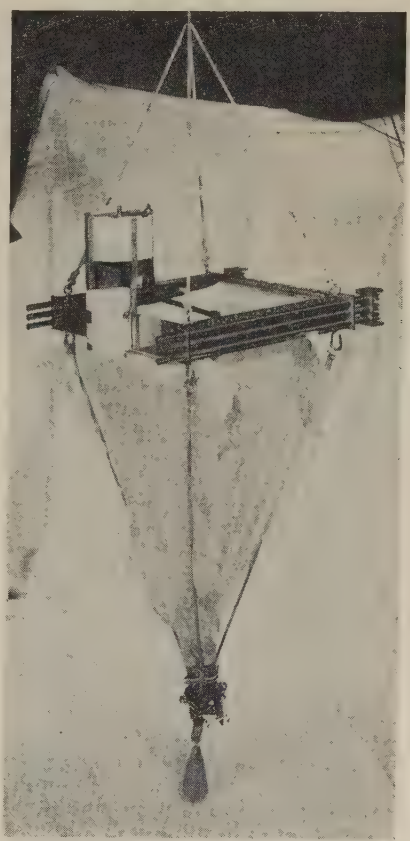

Fig. 1. Automatic opening-and-closing multiple net.

2. Construction

The mouth of the net opens at a square metal frame, 40 cm × 40 cm, and three inner metal tubes are equipped inside two sides of this frame located at the opposite positions. There are narrow grooves on the inner metal tubes by which small rods at both ends of the sliding plates are loosely supported (Fig. 2).

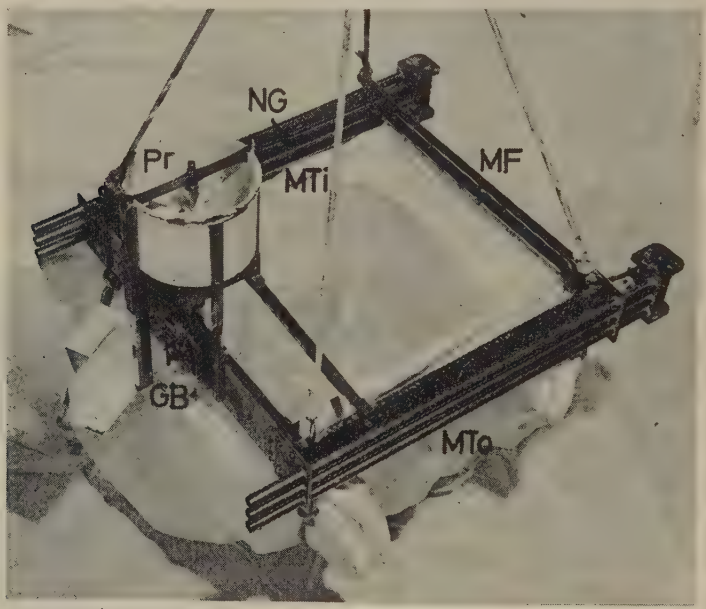

Fig. 2. Mouth opening of the net. GB, gear box; MF, mouth frame; MTi, inner metal tube; MTo, outer metal tube; NG, narrow grooves; Pr, propeller.

Thus, the sliding plates can easily slide in horizontal directions from one side to the opposite of the mouth frame. The sliding plates are pulled by the contraction of rubber strings which connect the end of the outer metal tubes and the sliding plates through pulleys at other end of the outer metal tubes (Figs. 2, 3).

A gear box is attached to one plate of the mouth frame. Reduction gears are set inside this box, and they are connected with a propeller (Fig. 6). The revolution of the propeller is created by the current of the water while the sampler is hauled. A cam on the auxiliary axile which is connected with the reduction gear, is gradually lowered, and in turn, three stoppers of the sliding plates are successively released (Fig. 4). At this moment three sliding plates are successively forced to move by the contraction of the rubber strings from one side to another of the mouth frame.

Fig. 3. Pulleys and rubber strings.

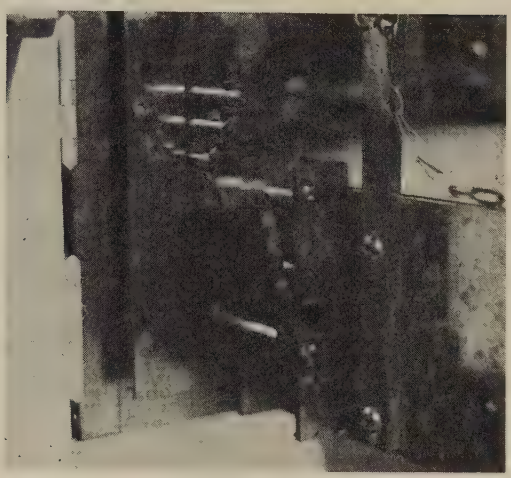

Fig. 4. Cams and triggers of the stopper of the sliding plates.

Four square nets, each about 160 cm long, made of bolting cloth GG54, 0.33 mm × 0.33 mm mesh apertures, are suspended from the sampler in the way that the first net is suspended from one side of the mouth frame and the first sliding plate; the second net is suspended from the first sliding plate and the second sliding plate, and so on. The one side of the fourth net is suspended from the other side of the mouth frame, so that the fourth net is never closed after it was opened. Plastic buckets, 4 cm in diameter, are attached to the cod end of the nets (Fig. 5).

When the sampler is hauled vertically from the depth of 1000 m, the first cam on the auxiliary axile in the gear box releases the trigger of the stopper of the first sliding plate after the sampler had been hauled for 250 m, and in turn, closes the first net. Thus the first to third nets are successively

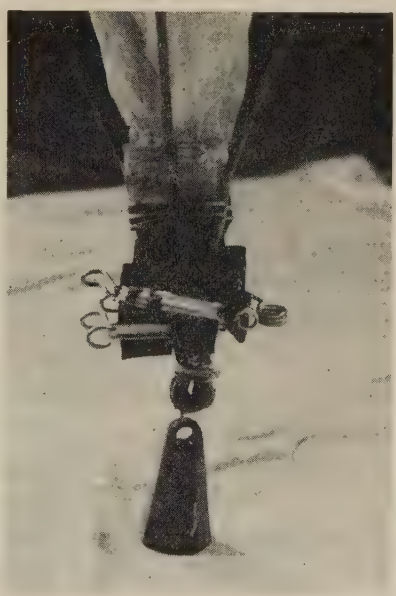

Fig. 5. Plastic buckets.

opened and closed at a interval of 250 m, and then the fourth net is open.

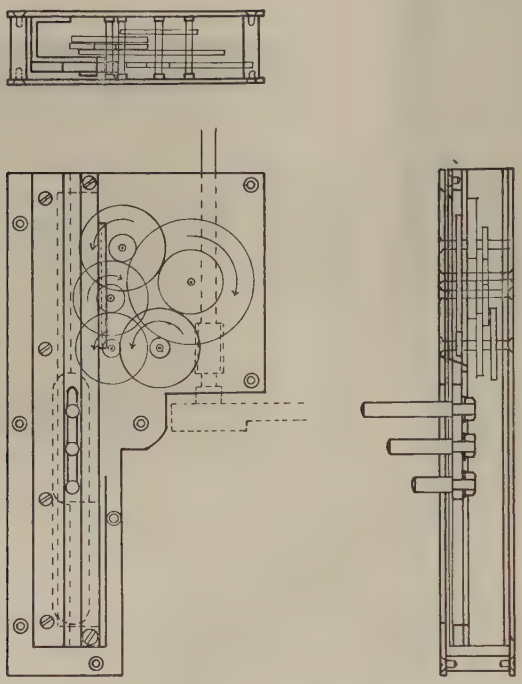

Fig. 6. Gear box.

3. *Field trial*

Trial sampling was carried out on Cruise 65-06 of the R/V Ryofu Maru of the Japan Meteorological Agency, off the east coast of Japan in the summer of 1965. The sampler was lowered by paying out a wire cable as long as 1000 m, and it was immediately raised at a speed of one meter per second. Angle of the wire was about 45°. It took about 40 minutes for lowering and about 17 minutes for raising the sampler. The operation was very easy.

It was felt to be desirable to lessen the resistance of the sampler against the water during the lowering, so that the time of lowering can be more saved. Installation of a flowmeter and depth recorder is desirable, though they were not equipped at the trial sampling.

Acknowledgements: The authors are much indebted to Prof. Sigeru Motoda, University of Hokkaido, for his helpful suggestions concerning the device of this sampler. Kind assistance given by the research staffs on board the R/V Ryofu

Maru of the Japan Meteorological Agency during the work at sea are also acknowledged. Cooperation of manufacturing the trial production by the Rigosha Co. Ltd., is greatly appreciated.

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Some Chemical Elements in the Japan Sea*

By

Mamoru Ohwada and Katsumi Yamamoto

Maizuru Marine Observatory

(Received September 5, 1966)

Abstract: The Japan Sea is one of the adjacent seas in the North Pacific Ocean, and it is open to the Pacific through two shallow straits (Tsushima Strait and Tsugaru Strait). Owing to the shallowness of the straits, the deep waters of the Japan Sea do not mix directly with the Pacific waters. Consequently, the distribution of chemical elements in waters is rather characteristic. Though the salinity in the sea water of the Japan Sea is close to that of the Pacific, the dissolved oxygen content in deep waters is remarkably large, and the distribution of oxygen resembles to that of the European Mediterranean Sea. We are going to discuss here on the distributions of the dissolved oxygen and the phosphate in the Japan Sea.

1. Dissolved oxygen

i) Horizontal distribution

We made maps (Fig. 1, 2) of the mean horizontal distribution of dissolved oxygen in each season. The maps were made by the data of the Maizuru Marine Observatory in seven years from 1959 to 1966. The numerals give the mean values in each square degree, and the lines show isolines of the oxygen content. We drew maps at different layers from the surface to the 1000 m layer, and the maps of 100 m layer are shown here as typical examples of them.

Fig. 1 is the map in summer. We can clearly distinguish here the difference between the Tsushima Warm Current and the Liman Cold Current by the dissolved oxygen content. Namely, the Tsushima Warm Current contains less than 6.0 ml/l runs along the coast of Japan Proper, and the waters in the Liman Cold Current

* Presented at the Eleventh Pacific Science Congress of the Pacific Science Association, held at the University of Tokyo, Japan, August—September 1966, and organized by the Science Council of Japan.

contain 6.5—7.2 m*l*/*l*. We can find the boundary zone between these two water masses.

In winter (Fig. 2) the area containing less than 6.0 m*l*/*l* is found only in the narrow southwest part, and almost all waters contain more than 6.0 m*l*/*l*. The increase of oxygen may be due to the decrease of the water temperature and the vertical mixing of the upper layer waters. The content in the northern part is almost the same as that in summer and show 6.5—7.2 m*l*/*l*.

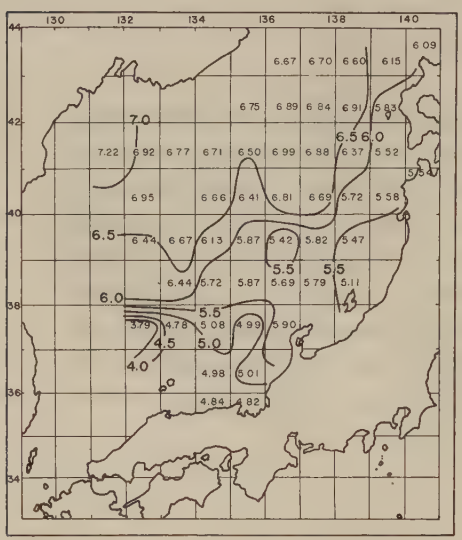

Fig. 1. Mean values of the dissolved oxygen content (m*l*/*l*) at the 100 m layer in summer.

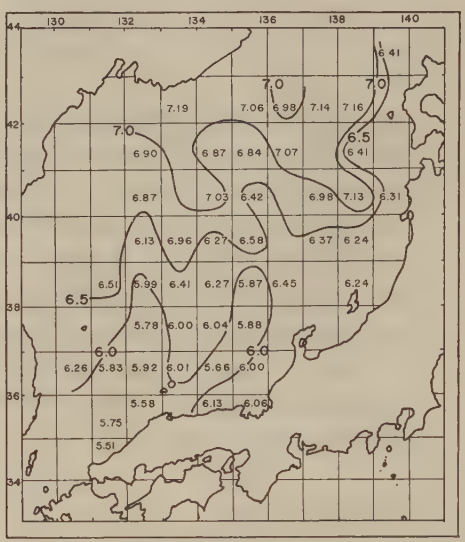

Fig. 2. Mean values of the dissolved oxygen content (m*l*/*l*) at the 100 m layer in winter.

ii) *Vertical distribution*

Fig. 3 shows the vertical distribution of dissolved oxygen along the cross section of the central part of the Japan Sea from southeast to northwest in August 1965. We can divide the waters into following seven water masses according to the contents of the dissolved oxygen. Namely, (1) warm upper layer water masses (4.7—4.9 m*l*/*l*), (2) warm water masses (5.0—5.5 m*l*/*l*), (3) Liman upper layer water masses (6.5—8.5 m*l*/*l*), (4) upper middle water masses (5.2—5.5 m*l*/*l*), (5) middle water masses (4.9—5.1 m*l*/*l*), (6) deep water masses (5.1—5.2 m*l*/*l*) and (7) bottom water masses (>5.2 m*l*/*l*). The concentration of the dissolved oxygen is changeable in the layers from surface to the upper middle

water layer which is 400—500 m deep. We can see the maximum value (8.0—8.5 ml/l) within the depth of 20—50 m in the Liman Cold Waters. There is a minimum value (4.9—5.1 ml/l) in the middle layer which is 600—1000 m deep.

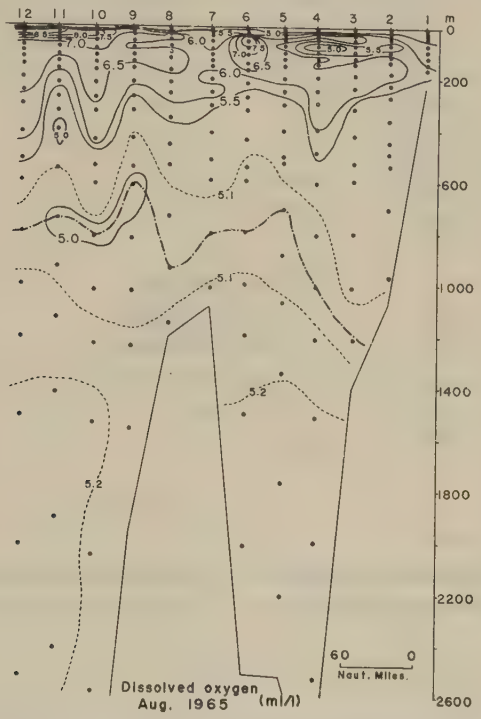

Fig. 3. Vertical distribution of dissolved oxygen (ml/l) along the cross section in the central part of the Japan Sea (along the line of 330° from Etizen Misaki).

Fig. 4 shows the seasonal variation of the vertical distribution of the dissolved oxygen at the station about 120 miles northwest of Noto Peninsula. The values in the upper 300 m layer change remarkably from spring to summer, but they do not fluctuate so much in the layer deeper than 400 m. The minimum layers are 500—700 m deep and the contents of oxygen are almost constant (5.0—5.1 ml/l) in them. The density (σt) at the minimum layer is 27.3 which is same as those in other seas.

The dissolved oxygen contents at the minimum layer in the seas around Japan are shown in Table 1.

It is to be noticed that the value in the deep water in the Japan Sea is re-

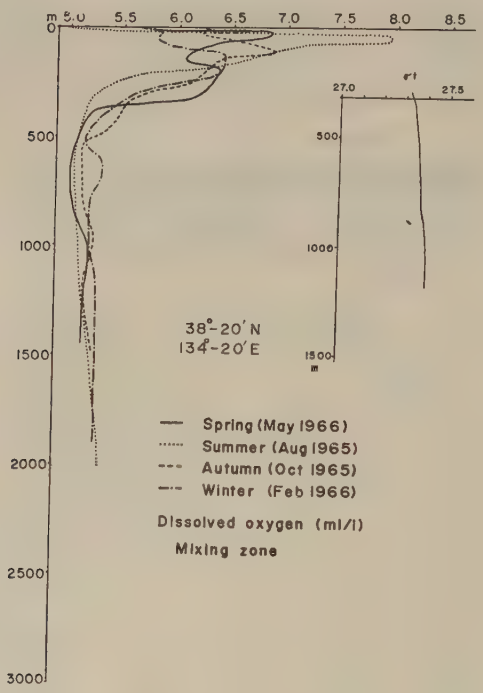

Fig. 4. Seasonal variation of the vertical distribution of dissolved oxygen at a station (38°20′N, 134°20′E).

Table 1. Dissolved oxygen contents in their minimum layers

Area	Dissolved oxygen (ml/l)
Western part of the Bering Sea	<0.5
Oyashio	0.5—0.8
Okhotsk Sea	1.0—1.25
Kuroshio	—1.5
Japan Sea	4.9—5.1

markably larger than those in other seas. The reason for this is that the exchange rate of the waters between the surface and the deep layer is larger in the Japan Sea than that in other seas.

2. *Phosphate in sea waters*

i) Vertical distribution of phosphate

Fig. 5 is a cross section showing the vertical distribution of phosphate-

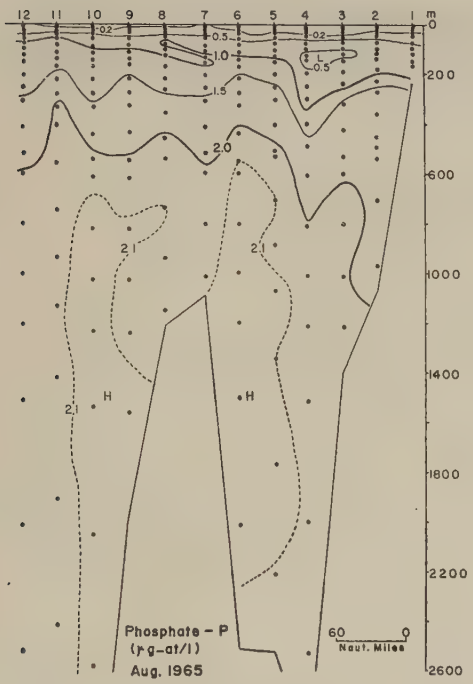

Fig. 5. Vertical distribution of phosphate-phosphorus (μg-at/l) along the cross section in the central part of the Japan Sea.

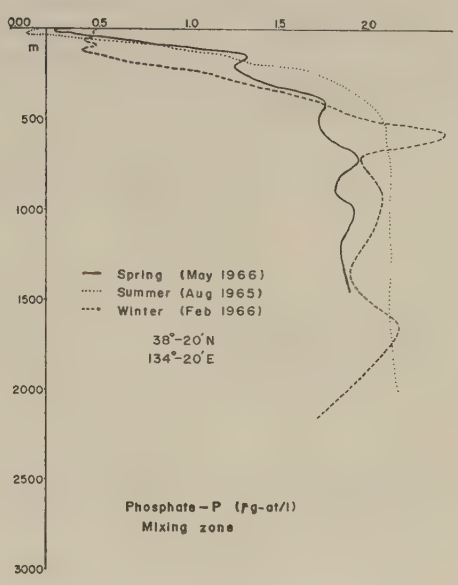

Fig. 6. Seasonal variation of vertical distribution of phosphate-phosphorus at a station (38°20′N, 134°20′E).

phosphorus in the Japan Sea. In the Tsushima Warm Current the value is 0.2—0.6 μg-at/l, and in the Liman Cold Waters it is 0.4—1.6 μg-at/l. In the layers below 500 m it shows 1.8—2.3 μg-at/l.

Fig. 6 shows a seasonal variation of the vertical distribution of the phosphate-phosphorus at the same station (38°20′N, 134°20′E) in the mixing area of the Japan Sea. The phosphate-phosphorus content in the Japan Sea is smaller than that in the Pacific Ocean, and it is rather close to that in the Atlantic Ocean. The maximum value is found at the same layers as the dissolved oxygen minimum.

ii) Conservative (reserved) phosphate

SUGIURA (1965) discussed on the distribution of reserved phosphate in the subarctic Pacific region and showed that the concentration of reserved phosphate is useful to study the circulation of water masses. Fig. 7 is a cross section

showing the vertical distribution of reserved phosphate in the Japan Sea. In the Tsushima Warm Current the value is 0.0—0.42 μg-at/l, and in the Liman Cold Waters it is 0.5—1.00 μg-at/l. In the layers below 500 m it is larger than 1.0 μg-at/l. In the minimum layer of the dissolved oxygen it is 1.0—1.3 μg-at/l.

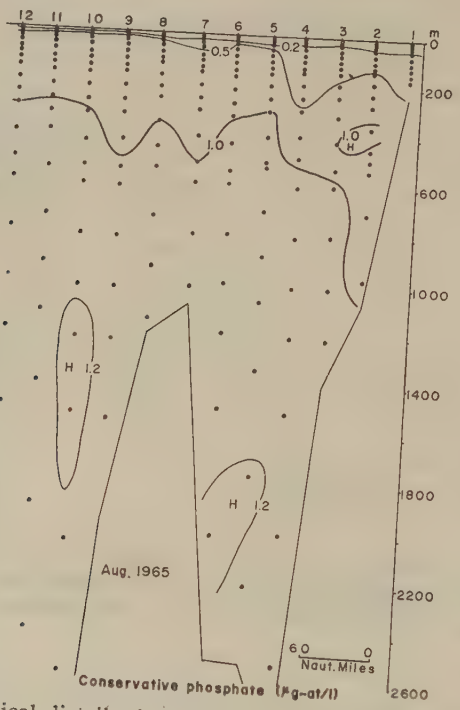

Fig. 7. Vertical distribution of reserved phosphate (μg-at/l).

In Tables 2 and 3, these results are compared with those in other water masses. The value of reserved phosphate in the Japan Sea is large next to the Oyashio.

Table 2. Concentrations of reserved phosphate in the various masses around Japan.

Area	Reserved phosphate (μg-at/l)
Oyashio	1.35—2.25
Kuroshio (East of Honshu)	0—0.17
Kuroshio (South of Kyushu)	0—0.13
Japan Sea	0—2.10
Tsushima Current	0—0.42
Liman Current	0.50—1.00

Table 3. Concentrations of reserved phosphate in the minimum layer of dissolved oxygen (σt=27.3).

Area	Reserved phosphate (μg-at/l)
South of Aleutian Is.	0.67—1.58
East of Honshu	0.60—1.28
South of Honshu	0.20—0.87
South of Kyushu	0.00—0.72
Japan Sea	1.00—1.36

From the both large values of concentrations of reserved phosphate above mentioned, it may be said that the exchange of waters between the surface and the bottom is fairly rapid as comparing with other seas.

Acknowledgement: The authors wish to express their hearty thank to Prof. Y. MIYAKE, Tokyo Kyoiku University and Meteorological Research Institute, who kindly read this manuscript before printing.

Reference

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Plankton in the Japan Sea

By

Mamoru Ohwada and Futomi Ogawa

Maizuru Marine Observatory

(Received September 5, 1966)

It is a well known aspect that there are two main currents in the Japan Sea. Namely, the Tsushima Warm Current flows from southwest to northeast along the coast of Honshu and the Liman Cold Current runs from northeast to southwest along the east coast of Asiatic Continent. The Tsushima Warm Current develops and spreads to the north from spring to summer and decays from autumn to winter. Accordingly, the distribution of plankton also fluctuates. We studied the microplankton on the basis of data obtained by the Maizuru Marine Observatory in eleven years from 1955 to 1965. The samples were concentrated by a centrifuge from about 330 m*l* of surface sea water. The individual numbers are represented as those per one liter of sea water.

Fig. 1 shows the standing crops in each season as representatives in these years. Fig. 1 a shows a condition in spring. The full lines are isolines of the individual number of microplankton. The broken lines show the isotherms at the 100 m layer, and the line of 10°C nearly coincides with the boundary line between the Tsushima Warm Current and cold waters in the offing. The microplankton is densely populated in the Tsushima Warm Current and near the boundary line showing the number up to 10^5 per liter, while it is smaller in the offshore cold waters. In summer (Fig. 1 b) the densely populated area moves northwards in the Tsushima Warm Current. In the offshore cold waters the population is still smaller. In autumn (Fig. 1 c) the individual number of microplankton is also larger in the Tsushima Warm Current than that in the offshore cold waters. In

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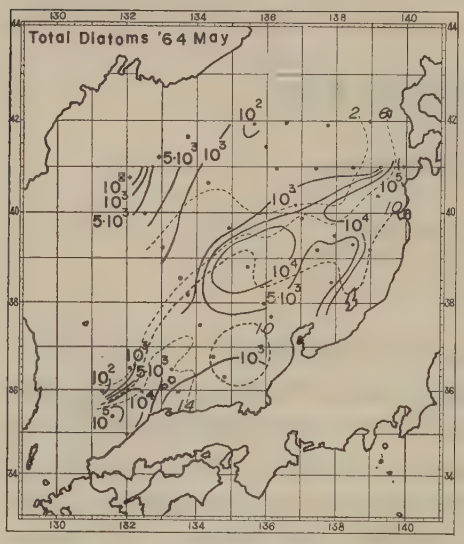
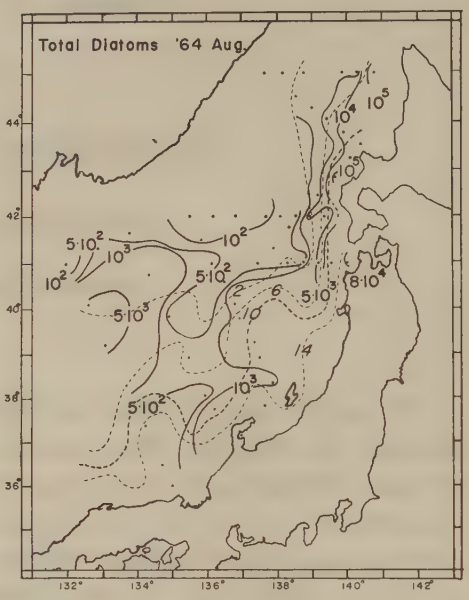
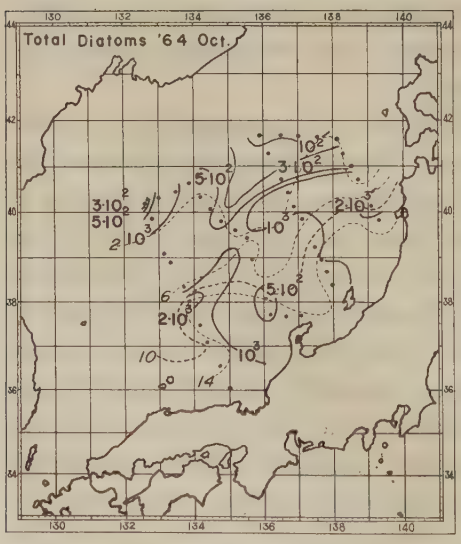
winter (Fig. 1 d) the same tendency as those in the previous seasons is recognized.



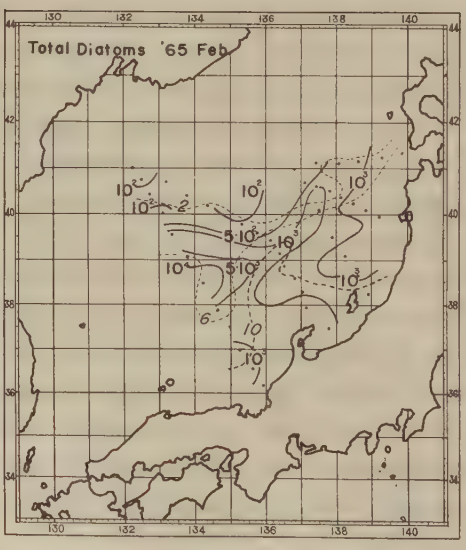
(a) Spring



(b) Summer



(c) Autumn



(d) Winter

Fig. 1. Isolines of total diatoms (ind. numb./one liter of sea water) at the surface layer (full line), and isotherms (°C) at the 100 m layer (broken line).

As mentioned above, the population of microplankton is larger in the Tsushima Warm Current than that in the Liman Cold Current all the year round. This is a remarkable difference between the Japan Sea and the Northwestern Pacific Ocean where the Kuroshio runs against the Oyashio. The reason for this is that

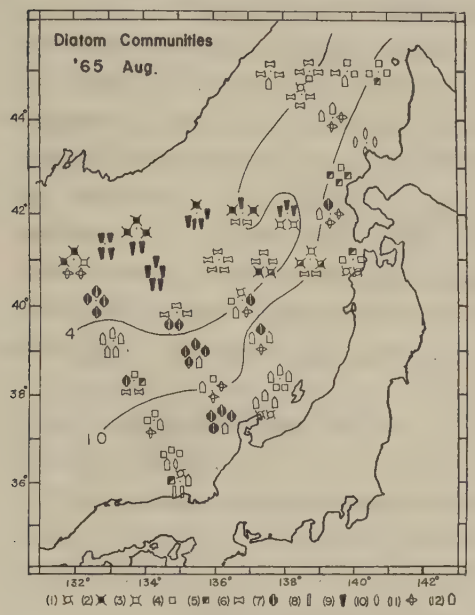


Fig. 2. Diatom communities at the surface layer represented by symbols and isotherms at the 100 m layer in summer.

(1) *Bacteriastrum varians*
(2) *Chaetoceros atlanticus*, etc.
(3) *Chaetoceros tetrastichon*
(4) *Chaetoceros affinis*, *C. curvisetus*, *C. didymus*, *C. lorenzianus*
(5) *Chaetoceros compressus*
(6) *Climacodium biconcavum*
(7) *Dactyliosolen mediterraneus*
(8) *Leptocylindrus danicus*
(9) *Licmophora abbreviata*
(10) *Nitzschia closterium*, *N. seriata*
(11) Pennatae misc.
(12) *Rhizosolenia alata*, *R. calcar avis*, *R. cylindrus*, *R. styliformis* v. *latissima*

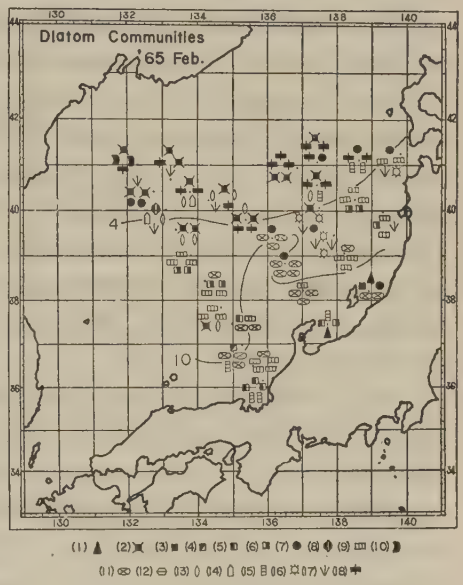


Fig. 3. Diatom communities at the surface layer represented by symbols and isotherms at the 100 m layer in winter.

(1) *Asterionella japonica*
(2) *Chaetoceros atlanticus*, etc.
(3) *Chaetoceros subsecundus*
(4) *Chaetoceros compressus*
(5) *Chaetoceros debilis*
(6) *Chaetoceros socialis*
(7) *Coscinodiscus excentricus*, etc.
(8) *Dactyliosolen mediterraneus*
(9) *Eucampia zoodiacus*
(10) *Fragilaria* sp.
(11) *Lauderia borealis*
(12) *Melosira sulcata*
(13) *Nitzschia seriata*, etc.
(14) *Rhizosolenia alata*, etc.
(15) *Skeletonema costatum*
(16) *Stephanopyxis palmeriana*
(17) *Thalassionema nitzchioides*
(18) *Thalassiosira nordenskiöldii*

the waters in the Tsushima Warm Current are nutritious than those in the pure Kuroshio Current. The Tsushima Warm Current is affected by the nutritious neritic waters in the East China Sea and the Yellow Sea before coming through the strait. Moreover there is a supply of nutritious deep waters by the upwelling caused by the bottom topography in the Tsushima Warm Current.

The distributions of indicative species in the water masses are shown in the Figs. 2 and 3. In the warm season: *Chaetoceros affinis*, *C. curvisetus*, *C. didymus* v. *anglica*, *C. lorenzianus*, *Leptocylindrus danicus* and *L. minimus* are abundant in the neritic warm waters. *Dactyliosolen mediterraneus*, *Rhizosolenia alata* f. *gracillima*, *R. calcar avis*, *R. styliformis* v. *latissima* and *Climacodium biconcavum* dominate in the offing warm waters. In addition, *Trichodesmium thiebauti* is also found. These warm water species spread widely to the western part of Hokkaido in summer. In the cold water masses, *Chaetoceros atlanticus*, *C. concavicornis*, *Rhizosolenia hebetata* f. *semispina* and *Parafavella pacifica* daminate.

In the cold season: *Chaetoceros debilis*, *C. socialis* and *Skeletonema costatum* are the dominant species in the neritic warm waters. *Eucampia zoodiacus*, *Lauderia borealis* and *Rhizosolenia stolterfothii* are densely populated in the offing warm waters. In the cold water masses, *Chaetoceros atlanticus* and *C. concavicornis* are still dominant. In addition, *Thalassiosira nordenskiöldii*, *Coscinodiscus excentricus* and *Parafavella pacifica* are also found.

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Determination of Ammonia in Sea Water by the Indophenol Method and its Application to the Coastal and Off-shore Waters

By

Takeshi SAGI

Japan Meteorological Agency

(Received September 27, 1966)

Abstract: A new indophenol method by LUBOCHINSKY and ZALTA has been examined for the purpose of the determination of ammonia in sea water, and the desirable condition for the analysis of ammonia in sea water has been found out. This simple and sensitive method is adequate to the determination aboard the research vessel. With a spectrophotometer, it is possible to detect the concentration as low as 0.05 μg-at/l.

This method has been applied routinely along the longitude of 144°E, February 1966. The lowest value of 0.03 μg-at/l was obtained at the axis of the Kuroshio Current. In Tokyo Bay ammonia content is roughly 200 times higher than the concentration in the open sea.

1. Introduction

For the determination of ammonia in sea water the method of WATTENBERG (1929) has hitherto been adopted in the Japan Meteorological Agency. However, this method can only be applied to the ammonia-rich coastal waters or sea waters which can be found in a certain time of the year. For sea waters except those mentioned above, the concentration of ammonia is too low to be determined by this method. So, a new method with the higher sensitivity has been desired.

A new method which has recently been established by LUBOCHINSKY and ZALTA (1954) for the colorimetric determination of ammonia seems to be applicable to the determination of ammonia in sea water. So, the present author has tried to find out the desirable condition in applying this method to the ammonia analysis of sea water. As the result, the condition which will be mentioned in this report has been decided as desirable.

In addition, some results of ammonia determinations carried out in the sea

east of Honshu and Tokyo Bay are described in this report.

Richards and Kletsh (1964) has recently reported another method which is adopted in the 2nd edition of a manual of sea water analysis by Strickland and Parsons (1965). In their report, the historical background concerning the ammonia determination of sea water is described, but they have not given any remark on the new method which will be examined here.

2. *Analytical method*

After the examination by the present author on the Lubochinsky and Zalta's method for the purpose of the application to sea water, the following reagents and procedures have been found satisfactory.

Reagents

Phenol sealed in an ampoule: Add about 0.5 g of zinc powder to 500 g of phenol and redistill in a vacuum. Store the redistilled phenol in a dark-coloured bottle. This phenol is stable for several months. Seal every 5 g of phenol in a dark-coloured ampoule.

Nitroprusside: Weigh out 25 mg of sodium nitroprusside and wrap up in a cartridge paper.

Antiformin: Use a solution of commercial antiformin containing 5 to 3% of active chlorine.

Since the solution decomposes slowly, its activity should be checked at times in the following way: Add a few grams of potassium iodide to about 50 m*l* of distilled water and pipette in 1.0 m*l* of antiformin solution. Add 0.25 m*l* of concentrated hydrochloric acid solution and titrate the liberated iodine with the 0.1 N thiosulphate solution. 1 m*l* of 0.1 N thiosulphate corresponds to 0.003545 g of active chlorine. If 12 m*l* of thiosulphate is used, active chlorine is about 4%.

Sodium hydroxide solution: Dissolve 25 g of dry pellets in 1 *l* of distilled water.

Standard ammonia solution (primary): Dissolve 0.6607 g of ammonium sulphate of guaranteed reagent quality in 1 *l* of distilled water. Add 0.2 m*l* of chloroform and store the solution in a dark-coloured bottle. 1 m*l* of this solution corresponds to 10 μg-atoms of ammonia-nitrogen.

Sea water for calibration: Use the sea water containing ammonia as lowest as possible which is filtered through Millipore HA filter.

The following solutions should be prepared for an immediate use aboard the

research vessel.

Phenol solution: Break a phenol ampoule in a flask and dissolve in 200 m*l* of distilled water. Dissolve one pack (25 mg) of nitroprusside in the solution.

Sodium hypochlorite solution: Pipette 5 m*l* of antiformin solution into a flask, add 100 m*l* of sodium hydroxide solution and dilute to 200 m*l* with distilled water.

Standard ammonia solution (secondary): Dilute to 100 times primary standard solution with distilled water. Pipette 10 m*l* of this solution into a 1-*l* measuring flask and dilute to the mark with the sea water to be used for calibration. 50 m*l* of this solution corresponds to 1.0 μg-at/*l* of ammonia-nitrogen in sea water.

Procedure

Add 2 m*l* of phenol solution to 50 m*l* of a sample in a 100-m*l* flask and swirl the solution. Add 2 m*l* of sodium hypochlorite solution and mix. Stopper the flask and set it aside at room temperature for 5 hours or longer even over night.

Measure the extinction of the supernatant solution in a 5-cm cell at wavelength of 630 mμ.

The sensitivity of this method varies with room temperature and individual batches of reagents. It is, therefore, desirable that the calibration is done by inserting the secondary standard solution (1.0 μg-at/*l*) every series of runs.

Calibration

Fig. 1 shows a relation between the absorbancy, A, and the concentration of ammonia, C, added to the solvent; either distilled water or sea water. In this figure, it is noteworthy that the absorbancy of sea water is larger than that of distilled water at C of zero and the curve for distilled water is somewhat steeper than is the curve for sea water, which means that in the case of distilled water the colour development is more remarkable than in the case of sea water. In other words, in the case of sea water, it is conceivable that some

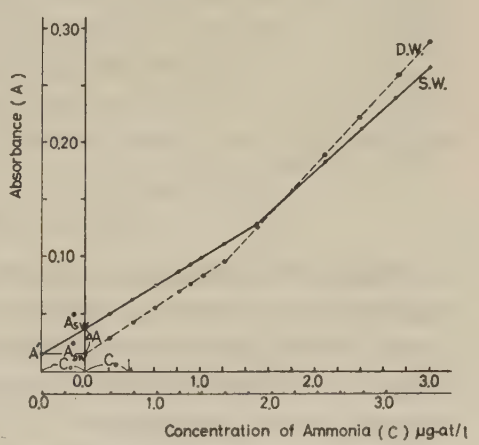

Fig. 1. A calibration curve (solid line) for the measurement of ammonia.

constituents of sea water inhibit the colour development. According to the author's examination, they seems to be calcium, magnesium and some others. But sodium chloride is not involved. Higher absorbancy for sea water than that for distilled water at C of zero may be ascribed to the ammonia existing prior to the addition in sea water. In fact, it is desirable that the ammonia-free, artificial sea-water is used as a solvent for preparation of standard ammonia solution. But, in most cases, reagents necessary for preparation of artificial sea water indicate the inherent contamination by ammonia and at the same time the tenacious resistance towards its removal. So, here, another method for the approximate calibration has been adopted.

The absorbancy of distilled water at C of zero, A°_{DW}, shows the reagent blank, which seems to be nearly equal to the reagent blank in sea water. Therefore, the difference of A°_{SW} and A°_{DW}, ΔA, corresponds to the extra ammonia existing prior to the addition into sea water. Now, the ammonia concentration equivalent to the absorbance of ΔA being sought, it may be approximately expressed, as far as the small value of ΔA is concerned, as follows: $C_0 = \Delta A \times \left[\left(\frac{dA}{dC}\right)_{SW}\right]_{C=0}$ where $\left[\left(\frac{dA}{dC}\right)_{SW}\right]_{C=0}$ shows the slope of a tangent to the curve for sea water at C of zero. In order to cancel the concentration, C_0, contained prior to the addition of the reagent into the sea water for calibration, suppose the exact location, A', to show the zero ammonia content having been obtained. A' must be on the straight line parallel to the abscissa and passing through the point, A°_{DW}, and the distance of A' to A°_{DW} must be equal to C_0. Connect A' and A°_{SW}. After that, move the original point to the left to the point showing the value of $-C_0$ on the abscissa. And adopt the new scale whose size is the same as the old one but is, as a whole, shifted as much as C_0 to the left. Then, the calibration curve can be obtained.

Notes

The distilled water in use was obtained by passing through an ion exchanger after distillation. Since the sensitivity of this method depends on the purity of phenol, phenol must be purified by re-distillation. Addition of the nitroprusside accelerates remarkably development of indophenol blue colour, but the blank increases if it is used too much.

Lubochinsky and Zalta (1954) concluded the desirable condition to be pH 12. But in the case of sea water, the pH value increases a little above pH 10

after the addition of some amount of an alkaline solution, and in addition there is no difference of extinction between pH 9.8 to 10.2 (Fig. 2). Hence, the buffer solution needs not to be used in the present method. The pH of the sea-water sample ranging from 7.5 to 8.35 becomes about 10 after the process mentioned above.

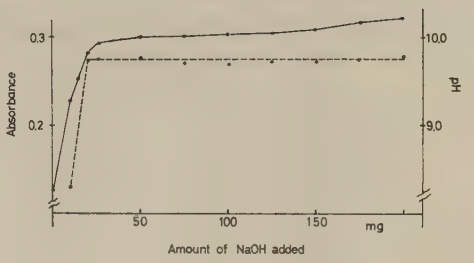

Fig. 2. Relation of sodium hydroxide amount to pH (broken line) and to absorbance (solid line).

The nitrite initially present does not change after the treatment. Urea dose not react. Glycine gives only 1 per cent of the extinction but L-glutamic acid as well as DL-Leucine gives 5% of the extinction. The existence of manganese ion tends to enhance, but copper ion inhibits, colour development. However, interferences by trace amount of metals in sea water are not likely to be important.

Sensitivity and Errors

With a spectrophotometer, it is possible to detect as low as 0.05 μg-at/l. Absorbance of the blanks are from 0.15 to 0.2 μg-at/l in a 5-cm cell. Six determinations of the standard solution using sea water as a dilutant with one batch of reagents on one day gave a standard deviation of about $\pm$0.02 μg-at/l at the level of 0.5 μg-at/l, $\pm$0.07 μg-at/l at the level of 1.0 μg-at/l, $\pm$0.08 μg-at/l at the level of 1.5 μg-at/l.

3. The nature of the ammonia distribution

The ammonia distribution in the off-shore waters (along the longitude of 144°E)

The northern branch of the Kuroshio Extension is mixing with the Oyashio waters in the eastern sea of Honshu, Japan. In this sea area periodical observation have been made by the R.V. Ryofu-maru of the Japan Meteorological Agency. The vertical distribution along the longitude of 144°E is convenient for knowing the characteristics of two main water masses. Fig. 3 shows the results of ammonia distribution obtained in February 1966. The integrating mean values derived from the individual observed values from the sea surface

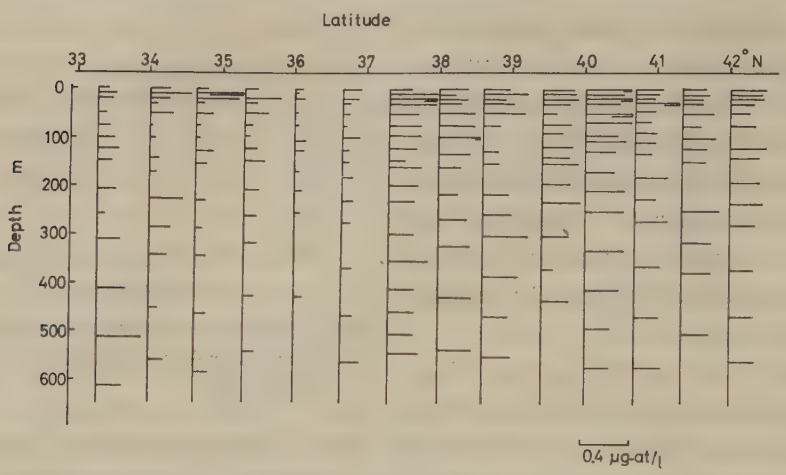

Fig. 3. Distribution of ammonia-nitrogen (μg-at/l) in the vertical section along the longitude of 144°E, February 1966.

to the depth of 600 m being calculated from the results shown in Fig. 3, the lowest values (0.03 μg-at/l) was found at about 36°N in the proximity of which the axis of the Kuroshio Current is located, a group of higher values (about 0.25 μg-at/l) to the north of 37°N, and another group of higher values (0.1～0.2 μg-at/l) to the south of 35°N.

Fig. 3 indicates that there are several maxima in the vertical distribution of ammonia unlike in case of phosphate. MENZEL and SPAETH (1962) observed a much more evident fluctuation. As compared with this, the present result seems to show a rather slight fluctuation. One or two maxima appeared approximately at the depths between 10 and 30 m in the upper layer where the homogeneous distributions of temperature and salinity were observed. This fact is quite interesting, because it suggests that the rate of the reaction to produce the ammonia maximum should be rather faster than that of mixing. In the deep water the other maximum values are found. The northern deep maximum (0.8 μg-at/l) appeared at about 2000 m, while on the other hand, the southern deep maximum (0.3 μg-at/l) at about 3500 m. On this cruise only three stations were occupied for the deep-sea observation. The above-mentioned results are obtained from a small number of data. So, the general trend must be confirmed by much more data in near future, but the results seem to suggest that the deep maximum, in general, appears at the shallower depth and takes a larger value to the north, while on the other hand, at the deeper depth and a smaller value to the south (Fig. 4).

Ammonia is rather more easily uptaken among inorganic forms of nitrogen by biomass and is produced from nitrate with a free energy decrease. Consequently, the once produced ammonia, in general, tends to decrease with time. So, in order to maintain a definite amount of ammonia, there must be a process to produce ammonia. According to VACCARO and RYTHER (1960), ammonia in sea water is produced through ammonification and nitrate reduction by bacteria and excretion by animal. As an example of ammonification by bacteria, VACCARO (1965) indicated that at south of Cape Cod, the maximum ammonia concentration occurred close to the bottom, which suggests an important nitrogen supply through the ammonification within the sediments.

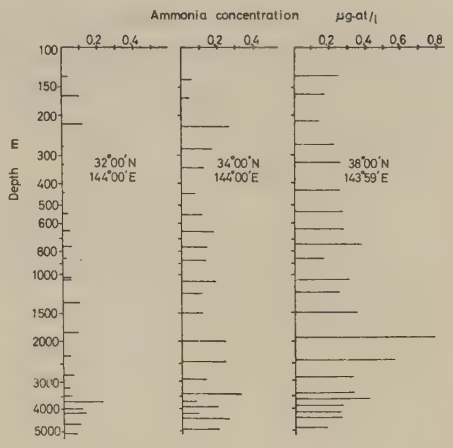

Fig. 4. Vertical profiles of ammonia-nitrogen (μg-at/l) in the western North Pacific, February 1966.

The ammonia distribution of the coastal waters

Besides the biological source mentioned above, the continental drainage as well as atmospheric precipitation plays an important role to a supply of ammonia to the ocean. The distribution of ammonia in Tokyo Bay are shown in Fig. 5. The ammonia content rapidly decreases from 51 to 0.23 μg-at/l with increasing salinity of 28 to 34% from the north to the south of the bay. Generally, in the open ocean, ammonia content is lower (0.5 μg-at/l) during the winter period. In Tokyo Bay,

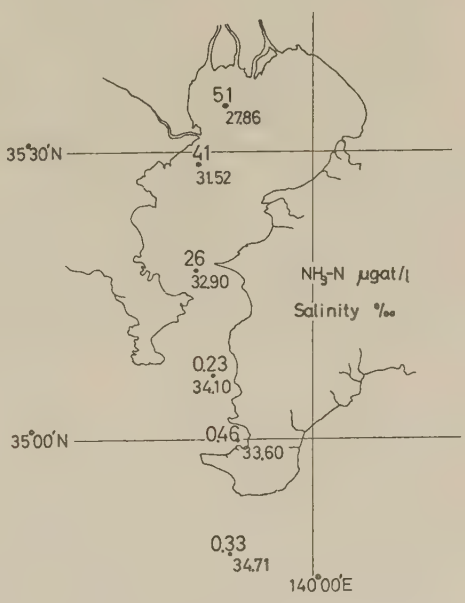

Fig. 5. Ammonia-nitrogen (μg-at/l) and salinity (‰) at the surface in Tokyo Bay, February 1966.

which is an example of the artificially polluted, coastal regions, ammonia content is roughly of the order of 100 times higher than the concentration in the open sea. Therefore, ammonia is thought to be of great use as an indicater of water pollution.

4. Discussions

The procedure mentioned here is simpler and the blank is lower in estimating ammonia in sea water than other method, and many samples can be dealt rapidly aboard the research vessel.

The method of calibration mentioned in this report is a simplified one contrived under some assumptions. So, strictly speaking, the further examination by using an artificial sea-water completely free from ammonia must be needed in future.

In this method, some kind of amino compounds might be reactive to some extent. In this connection, a complete survey of the behaviour of nitrogenous compounds likely present in sea water must be done but here it has not been made. So, it must be studied later. This method is recommended by the reason of the advantage of its higher sensitivity as well as simplicity.

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Cruise Report of CSK Survey by JMA in 1965

By

Hideo Akamatsu and Tsutomu Sawara

Japan Meteorological Agency

(Received October 11, 1966)

A semi-synoptic oceanographic survey was done by the Marine Division of the Japan Meteorological Agency (JMA) in cooperation with four marine obser-

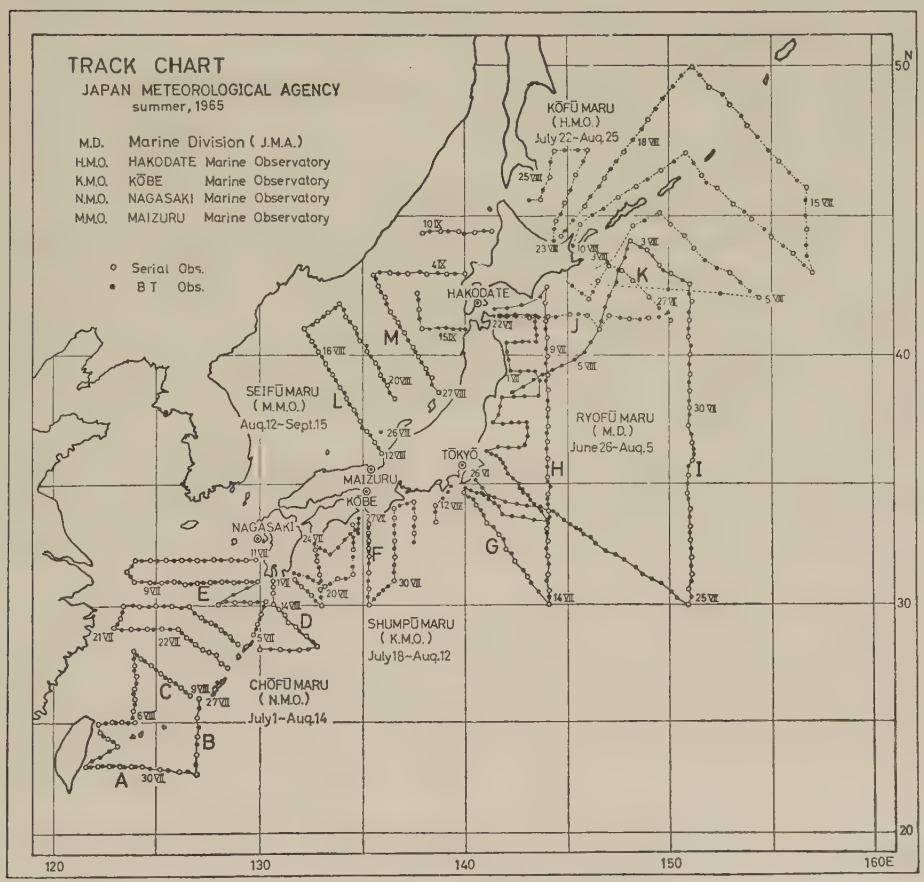

Fig. 1. Track chart, Japan Meteorological Agency, summer, 1965.

vatories of the JMA in the adjacent waters of Japan in summer, 1965 (Fig. 1). The survey forms fairly large part of the synoptic survey of the international program "Cooperative Study of the Kuroshio and Adjacent Regions (CSK)". Thirteen sections designated by capital letters in Fig. 1 have been declared for the CSK program. Research vessels participating in the survey are as follows.

Vessel	Agency	Gross tonnage	Length (m)	Chief scientist	Declared section
Ryofu Maru	Marine Division, JMA, Tokyo	1,200	74	T. SAWARA	G, H, I
Shumpu Maru	Kobe Marine Observatory	152	32	S. KONAGA	F
Chofu Maru	Nagasaki Marine Observatory	265	42	T. YAMAGATA	A, B, C, D, E
Kofu Maru	Hakodate Marine Observatory	335	47	H. IIDA	J, K
Seifu Maru	Maizuru Marine Observatory	355	48	M. YASUI	L, M

Items of Observations

(A) Observations between oceanographic stations while underway:
Echo-sounding
BT and GEK observations
Ordinary elements of maritime meteorology:
wind; air temperature; humidity; barometric pressure; weather; cloud; visibility; sea and swell at the standard time defined by WMO

(B) Observations at oceanographic stations

Sampling depths are 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 1000, 1200, 1500, 2000, 2500, 3000, 3500, 3750, 4000, 4250, 4500, 5000 m and so on.

The maximum depth of sampling is usually 1500 m and some deep hydrographic stations were occupied. Chemical analysis was made for salinity, oxygen content, pH, phosphate, and sometimes silicate, nitrate, nitrite, and ammonia-N etc.

Zooplankton sampling was done at each hydrographic station by a Norpac Net (GG 55) hauled from the depth of 150 m to the sea surface, and at some selected stations by an automatic opening-and-closing multiple net hauled from the depth of 1000 m to the sea surface. The water sample (500 cc) for phytoplankton study was taken from each standard depth in the upper 500 m layer at selected stations.

Seasonal observation of the Kuroshio south of Kyushu

A regular observation has been and will be made on the section southeast

of Yaku-shima, south of Kyushu, in order to see the seasonal fluctuation of the Kuroshio. The observation started in May 1965 and the hydrographic section was made six times in 1965 as follows.

Date	Vessel	Agency
15–17 May	Shumpu Maru	Kobe Marine Observatory
1–2 July	Chofu Maru	Nagasaki Marine Observatory
12–13 August	Chofu Maru	Nagasaki Marine Observatory
25–26 September	Chofu Maru	Nagasaki Marine Observatory
1–2 November	Chofu Maru	Nagasaki Marine Observatory
11–12 November	Shumpu Maru	Kobe Marine Observatory

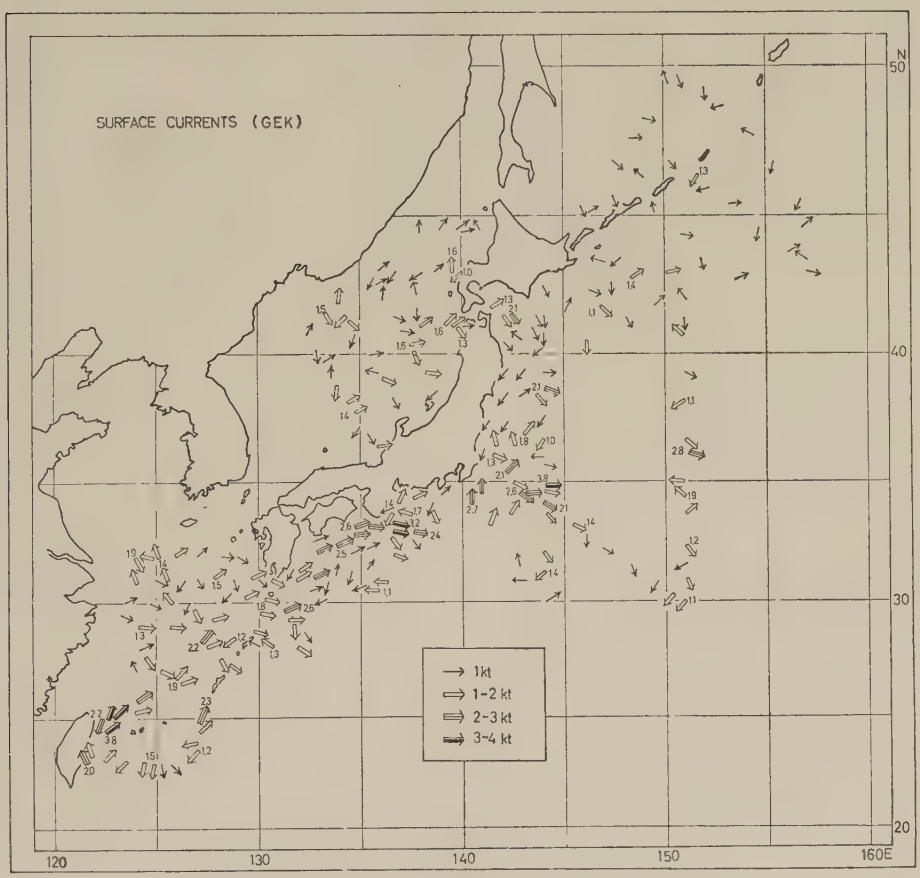

Fig. 2. Surface current measured with GEK.

Data report

Fig. 2 and 3 show the surface current by GEK and the temperature at the depth of 100 m by BT.

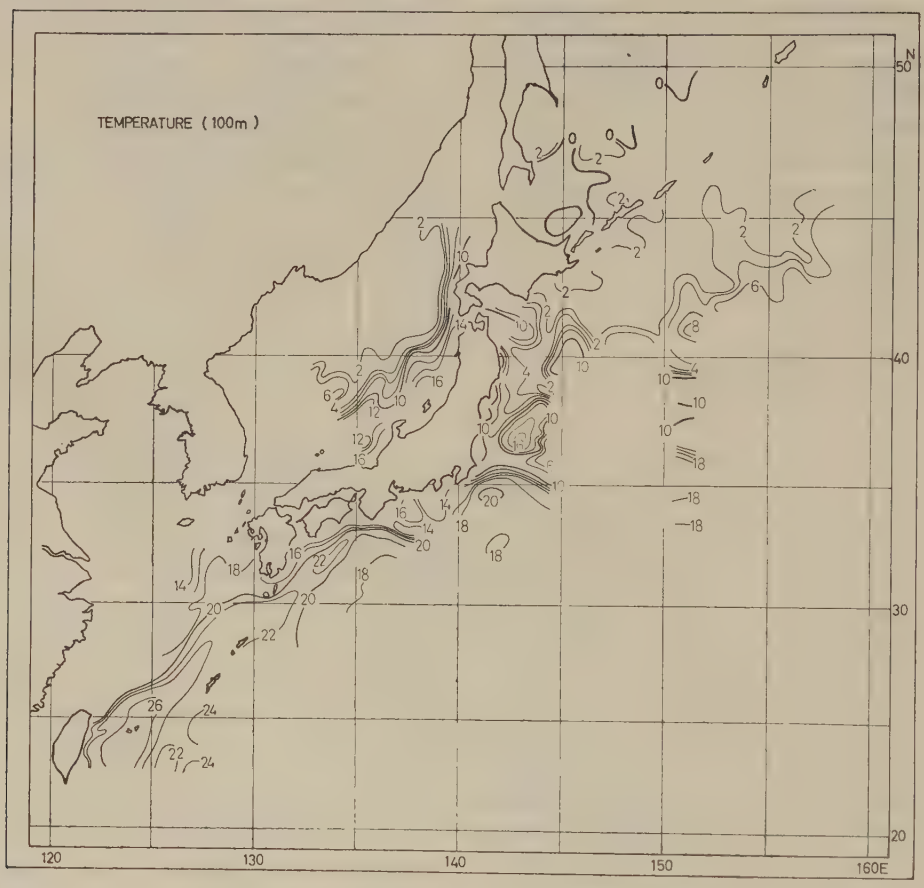

Fig. 3. Water temperature at the depth of 100 m.

The final data reports of these surveys will be seen in the volumes "The Results of Marine Meteorological and Oceanographical Observations, No. 37 and No. 38" to be published by the Japan Meteorological Agency. The physical and chemical data obtained by hydrographic casts have been submitted to the Kuroshio Data Center, Hydrographic Division, Japan Maritime Safety Agency, Tokyo.

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Uranium and Thorium in Antarctic Glacial Marine Sediments

By

Yukio Sugimura

Meteorological Research Institute, Suginami, Tokyo

and

Ernest E. Angino

State Geological Survey, University of Kansas, Lawrence, Kansas

(Received October 28, 1966)

Abstract: The content of uranium and thorium in Antarctic glacial marine sediments collected in the areas of the Ross, Bellingshausen and Amundsen Seas were determined. The average figure of uranium and thorium is 2.1 ppm and 8.3 ppm, respectively, with an average Th/U ratio of 4.6 was obtained. It is to be noted that an interesting geographical distribution of uranium and thorium was found in the area studied.

Sedimentation and chemical data for Antarctic sediments are extremely limited and as a rule only a general portrayal of sediment types from this area has been presented in the literature (Hough, 1956; Stetson and Upson, 1937).

In general, Antarctica is encircled by three sediment bands, each with its own geochemical characteristics (Angino, in press). We are concerned here only with the innermost of these three bands, a 200~400 miles wide band of a unusual type of marine sediment which has been laid down directly from a continental ice sheet with little or no modification. This innermost band of sediments, to which Pirie (1913) appended the name glacial marine sediment, is essentially correlative in position with the present maximum extent of the pack ice.

The sediment materials studied are representative of three geographical areas, from which samples are quite rare. These areas are the Ross Sea (6 samples), Amundsen Sea (2 samples) and Bellingshausen Sea (5 samples) as shown Figures 1 and 2. Although considerable information is available concerning the uranium and thorium content of recent marine sediments (Koczy, Goldberg etc.) from

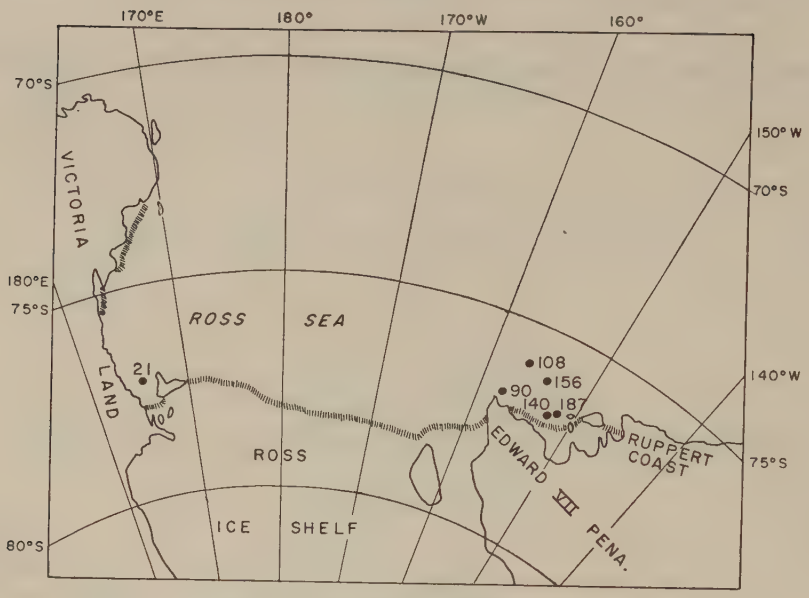

Fig. 1. Location of core sampled.

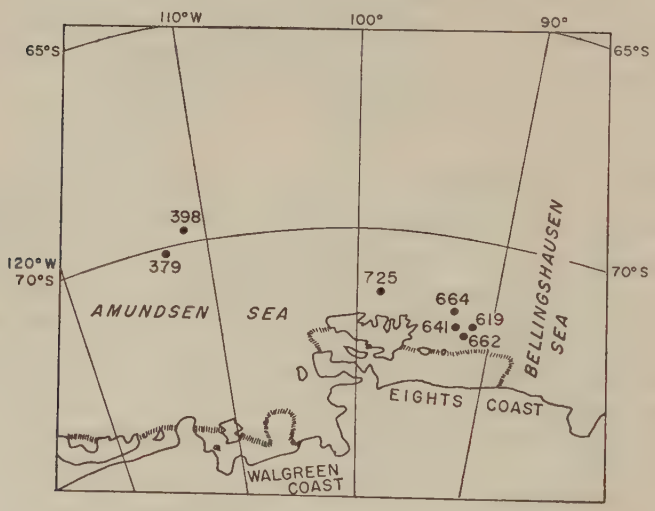

Fig. 2. Location of core sampled.

temperate latitudes, little is known of the concentration and distribution of uranium and thorium in Antarctic glacial marine deposits. The primary purpose of this study was to determine for the first time the uranium and thorium content of this unique sediment type and to obtain are preliminary data on the

distribution of the natural radioelements in the Antarctic area.

One to two grams of dried sediment was digested with concentrated hydrochloric acid, nitric acid and mixed solution of nitric acid and hydrofluoric acid successively, and the leachate was taken to dryness on a hot plate. Subsequently, the residue was dissolved in 6 M HCl for uranium determination and in 5 M HNO_3 for thorium determination, respectively.

Content of uranium was determined by absorption spectrophotometric method with PAR (4, 2-Pyridylazo-resorcinol) after separating it with an anion exchange resin by the hydrochloric acid and methanol mixed solvent system (Tera and Korkisch, 1961; Marple, 1964).

Thorium was isolated from the solution by means of an anion exchange resin by the nitric acid and methanol mixed solvent system. Then the content of thorium was analyzed by absorption spectrophotometric method with Arsenazo-III (2, 7-Bis [(azo-2)] phenylarsono-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid, disodium salt).

The results summarized in Table 1, shown than compared to the average uranium and thorium content of igneous rocks 3.0 ppm and 11.4 ppm respectively,

Table 1. Uranium and thorium in recent Antarctic sediments*.

Core No.	Sample No.	Location	Water Depth (m)	Depth in Core (cm)	U (ppm)	Th (ppm)
S I-3	21	77°31′S 160°34′E	448	9–14	2.11±0.06+	4.52±0.13+
S I-14	90	77 06 158 17 W	201	6–12	2.26±0.7	8.22±0.20
S I-19	108	76 01 156 44	3,477	5–10	3.22±0.10	12.7 ±0.4
S I-23	140	77 16 152 22	210	0– 5	1.61±0.05	12.1 ±0.3
S I-25	156	76 30 153 53	549	0– 7	3.88±0.12	14.4 ±0.4
S I-28	187	77 16 152 22	265	6–12	1.95±0.06	10.3 ±0.3
S I-41	379	70 07 112 58	3,684	7–12	1.26±0.05	3.79±0.11
S I-43	398	69 43 111 26	3,526	5–10	2.92±0.09	6.81±0.20
S I-57	619	72 28 91 43	159	0–9	0.47±0.02	2.81±0.08
S I-60	641	72 14 92 45	410	5–10	1.63±0.05	9.00±0.27
S I-63	662	72 41 91 55	516	5–10	1.77±0.03	10.0 ±0.3
S I-64	664	71 45 92 54	410	0–5	1.13±0.04	7.88±0.23
S I-69	725	71 14 98 30	260	0–9	1.44±0.04	5.04±0.15

+ Estimated analytical error.

* Samples SI 3, 14, 19, 23, 25 and 28 are from the Ross Sea.
,, SI 41 and 43 are from the Amundsen Sea.
,, SI 57, 60, 63, 64 and 69 are from the Bellingshausen Sea.

with an average ratio of thorium to uranium 3.8 (ADAMS *et al.*, 1959), the uranium and thorium content of recent Antarctic glacial marine sediments is slightly less, but the ratio of Th/U is concerned, it is slightly high.

A calculated overall average figure of uranium and thorium is 1.97±0.92 ppm and 8 27±3.61 ppm, respectively, with an average Th/U ratio of 4.19 for these sediments was obtained. No correlation of the depth of water was noted.

As can be seen Table 1, those samples from the vicinity of Edward VII Pens. (SI 19-25) show higher values than the others, for both uranium and thorium. The sample from off Eights Coast (SI-57) shows a quite low value of 0.47 ppm for uranium and 2.81 ppm for thorium respectively. Excepting these samples, fairly constant value of uranium was obtained from other areas. But the thorium content shows a wide distribution of values from 2.8 ppm to 14.4 ppm.

However, an interesting geographical distribution appears if the data is broken down further. As to the uranium content, the average of the Ross Sea samples (collected over 8° of longitude) is 2.5 ppm (6 samples); for Amundsen Sea is 2.1 ppm (based on 2 samples); and Bellingshausen Sea (5 samples) is 1.3 ppm. And the average content of thorium is 10.4 ppm for the Ross Sea sample; 5.3 ppm for the Amundsen Sea sample; and 6.9 ppm for the Bellingshausen Sea sample, respectively. Therefore, the average ratio of thorium to uranium is 4.1 for the Ross Sea sample, 2.5 for the Amundsen Sea sample and 5.4 for the Bellingshausen Sea sample, respectively.

These differences admittedly based on few samples are still large enough to suggest a real geographical difference in the uranium and thorium content of these sediments.

TUREKIAN (1961) gives following averages for the uranium and thorium content of different type materials.

		U ppm	Th ppm
Igneous Rock	Ultrabasic	0.001	0.004
	Basaltic	1.0	4.0
	Granitic		
	High Ca	3.0	8.5
	Low Ca	3.0	17
	Syenites	3.0	13
Sedimentary	Shales	3.7	12
	Sandstones	0.45	1.7
	Carbonates	2.2	1.7
	Deeper Sediments	1.3	7.0

The most recent figure for the crustal abundance of uranium (2.7 ppm) and thorium (9.6 ppm) is given by TAYLOR (1964). If we consider these data, then some interesting speculation results.

First, the carbonate content of glacial marine sediments as a type is quite low (ANGINO, in press). Furthermore, these sediments commonly have a large clay fraction. Considering these facts, it appears then that those areas supplying the sediments to those glaciers feeding the Ross Ice Shelf (melting which supplies the majority of recent sediment for Ross Sea) must be high in Granites, Syenites or Shales. Another alternative is that uranium and thorium are fixed anyhow from the water by organic or inorganic suspensions; however these sediments as a type are also quite low in organic material. Consequently, for uranium, such fixation seems to be most unlikely to occur. And as to the thorium, the leachable thorium in the sediment by digesting of hot concentrated hydrochloric acid is less than 1 ppm, and much less than other pelagic sediments. Then, a continental source for the high uranium and thorium content seems most probable. Continuing to the east, on the other hand, the extremely low value for the Bellingshausen Sea suggests a source in a basic rock. The average value of 1.29 ppm for uranium and 6.95 ppm for thorium is essentially equal to that of deep sea sediments, which however are completely different in character than glacial marine sediments. The only reasonable explanation of the low content of uranium and thorium found in the Bellingshausen Sea would seem to be a sediment source is low in uranium and thorium.

Although the average uranium and thorium content for the Amundsen Sea sediments (2 samples) does fall between that of the other two areas just mentioned. But, no discussion appears warranted as only two samples were available.

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A Deep Current Measurement in the Japan Sea*

By

Tosio NAN-NITI *Meteorological Research Institute*
Hideo AKAMATSU *Japan Meteorological Agency*
Takeo YASUOKA *Maizuru Marine Observatory*

(Received October 31, 1966)

Abstract: A 4-day series of measurements of deep current with a neutrally-buoyant float at 800 m depth was made at 39°48.7′N, 131°43.7′E, a western part of the Japan Sea.

The mean of the current measurements was 1.5 cm·sec^{-1} towards 235° true. It exhibited an inertia oscillation of about 19 hr period.

1. *Introduction*

The general circulation in the Japan Sea shows the anticlockwise direction, and we used to take the depth of no motion to be 300 to 400 m depth for the dynamical calculation assuming the waters below this layer is homogeneous and at rest.

In this observation, we select the depth of measurement to 800 m deep to check the movement of the oxygen minimum layer or the deep homogeneous water.

2. *Observation*

During from 30 th May to 3 rd June 1966, a float was used in making the current measurement, loaded for 800 m depth.

An anchored buoy (NAN-NITI *et al.*, 1964) was set at the location 39°48.7′ N, 131°43.7′ E, the depth was about 3,160 m (Fig. 1). This bottom-area is fairly flat and its depth showed 3150±50 m within a radius of 5 miles. The relative position of the float to the anchored buoy could be generally determined with an error of less than 0.1 miles.

The float was tracked for 96 hr, its track is shown in Fig. 2. Each dot, ○,

* JEDS Contribution No. 79

in this figure represents a three-bearing fix whose circle of error is generally less than about 50 m.

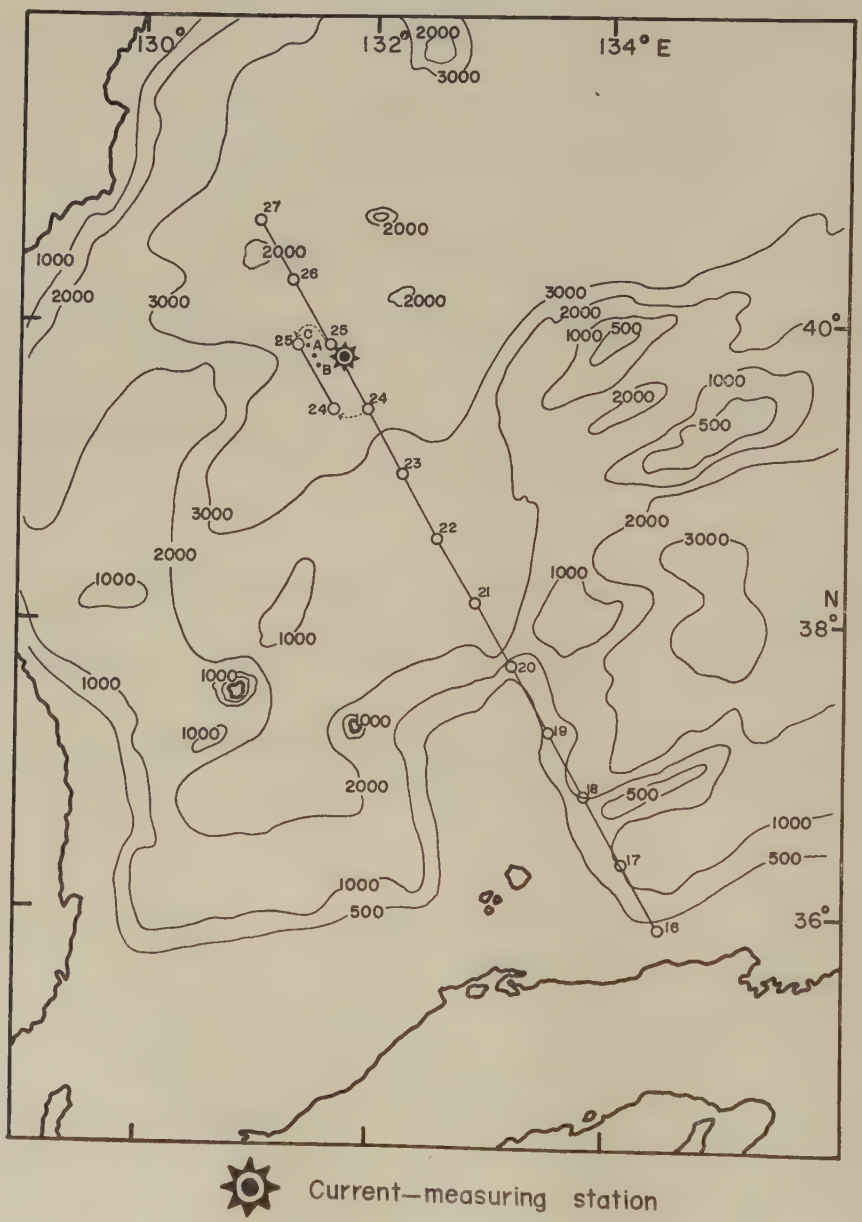

Fig. 1. Locality chart.

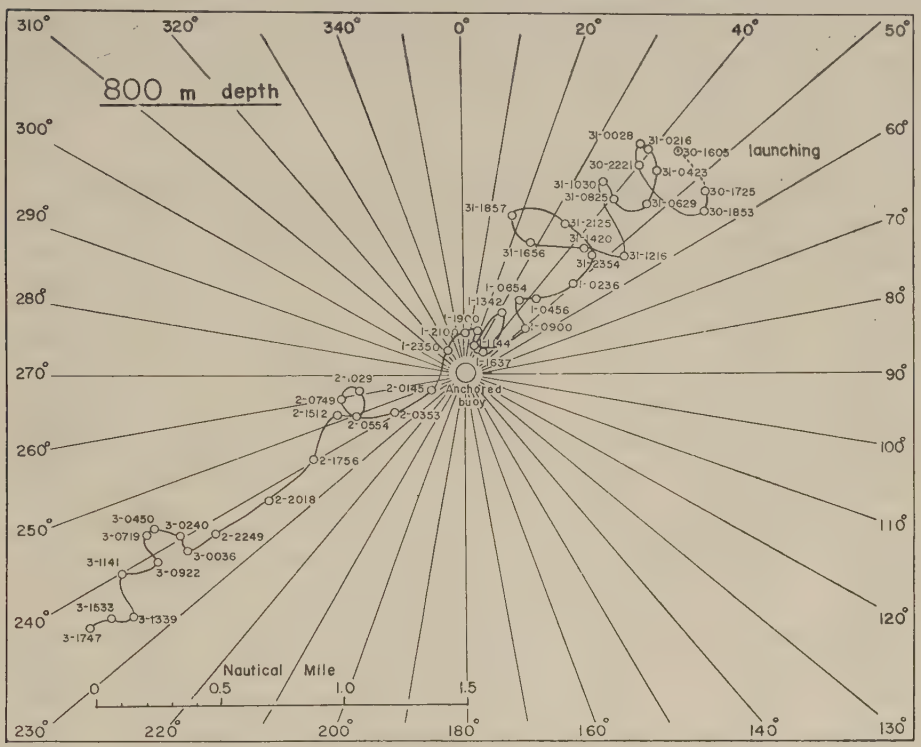

Fig. 2. Track of float. Each dot represents a three-bearing fix, the date and time of each fix is indicated.

3. *Results*

The track shows a straight run plus an oscillative motion. The mean current has been obtained by plotting the north-south and east-west components of displacement separately against time, fitting straight lines by least squares, and combining the slopes of these lines to give the resultant current and its direction (Fig. 3). The obtained mean current is 1.5 cm·sec^{-1}, bearing 235° true.

After the translational component has been removed, the orbital motion is shown in Fig. 4. It is rather complicated, but a periodic fluctuation can be seen in the residual, the period and amplitude of principal motion are estimated at about 19 hr and 700~800 m, respectively. It moved in a clockwise elliptical orbit at speed of about 3.5 cm·sec^{-1} with a 700 m of the major axis and 400 m of the minor one.

The half-pendulum day at 39°47′ latitude, the mean location of observation,

is 18 h 42 m, and its diameter of the inertia motion is 780 m provided its speed is 3.5 cm·sec^{-1}. The observed oscillative motion shows a good agreement with the theoretical values.

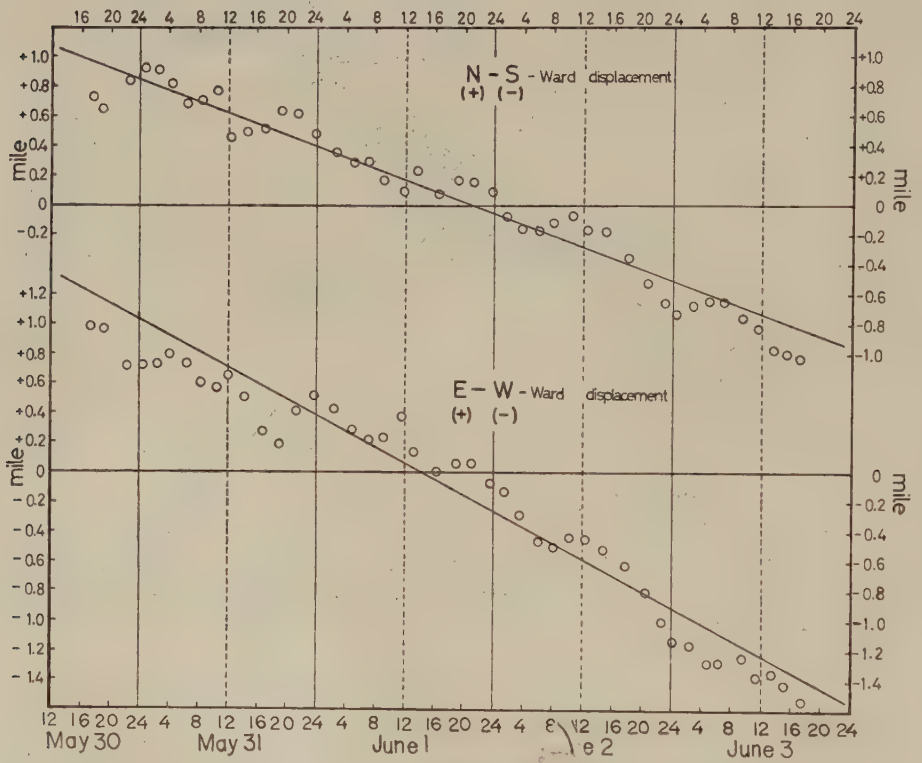

Fig. 3. Components of displacement of float plotted against time.

4. Estimating of the depth of float

The bearings were taken from different ship's positions to decide a float's position in horizontal plane assuming the constant depth of the float to be 800 m. Conversely, the scattering of bearings could estimate the depth of float to be 800±150 m assuming the some definite distance in horizontal plane between the ship and the float.

By another method, the expected depth which the float was made neutrally-buoyant by added weights was calculated to be 799 m from observations of temperature and salinity.

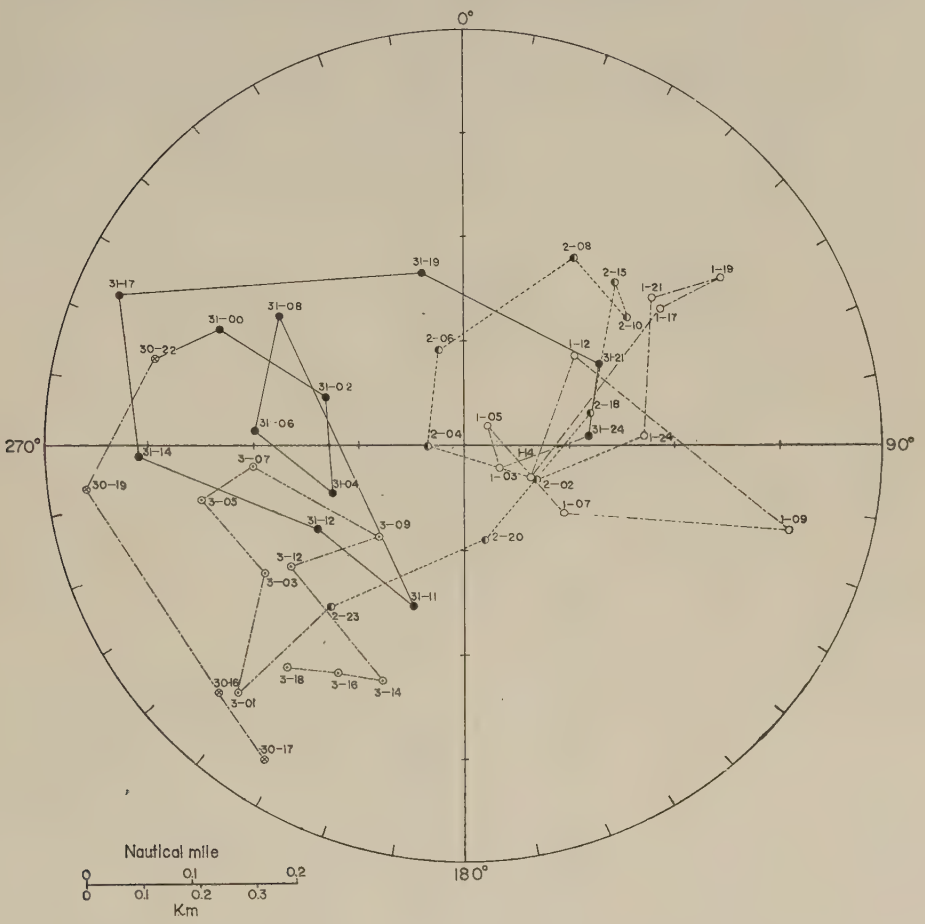

Fig. 4. Orbital motion of float. The unit of co-ordinates is nautical mile. The date and time of each fix is indicated.

5. *Hydrography*

At three hydrographic stations A, B, C, temperatures, chlorinities, quantities of dissolved oxygen and surface currents were observed (Fig. 5). The observed surface currents were weak, so we are afraid that some of them may show unreliable directions, and we can not have any definite conclusion about the surface current.

The dynamically calculated velocities of sections CA and AB refered to 1,500 m depth are shown in Fig. 6. The most probable geostrophic current at the station A may be 6.3 cm·sec^{-1} towards 63° true obtained by vector sum of

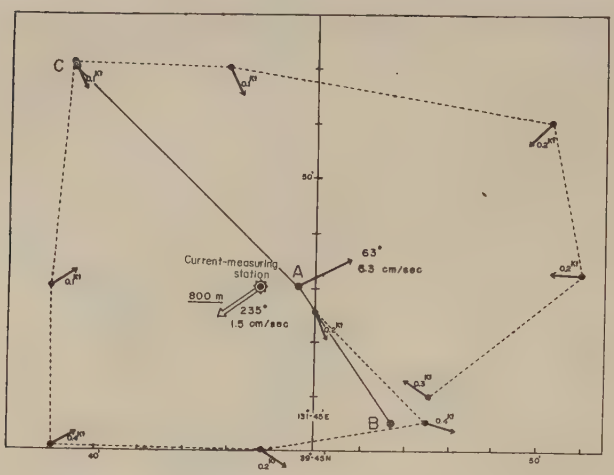

Fig. 5. Hydrographic stations near the current-measuring station.

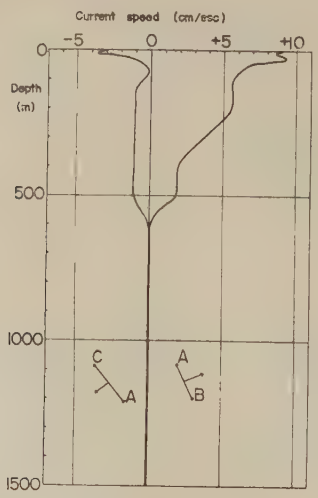

Fig. 6. Geostrophic currents in sections CA and AB.

the above two calculated ones (Fig. 5).

Temperature, chlorinities and quantities of dissolved oxygen are shown along the stations 16 to 27 (Figs. 1, 7). There is the oxygen minimun layer at about 800 m depth. The vertical distributions of them at the stations A, B, C are also shown in Fig. 8.

These figures suggest that there is some front at about stations 23, 24, and the homogeneous water occupies the depths deeper than 800 m. It is supposed that a cold water along the continental coast surrounding the northwest of the

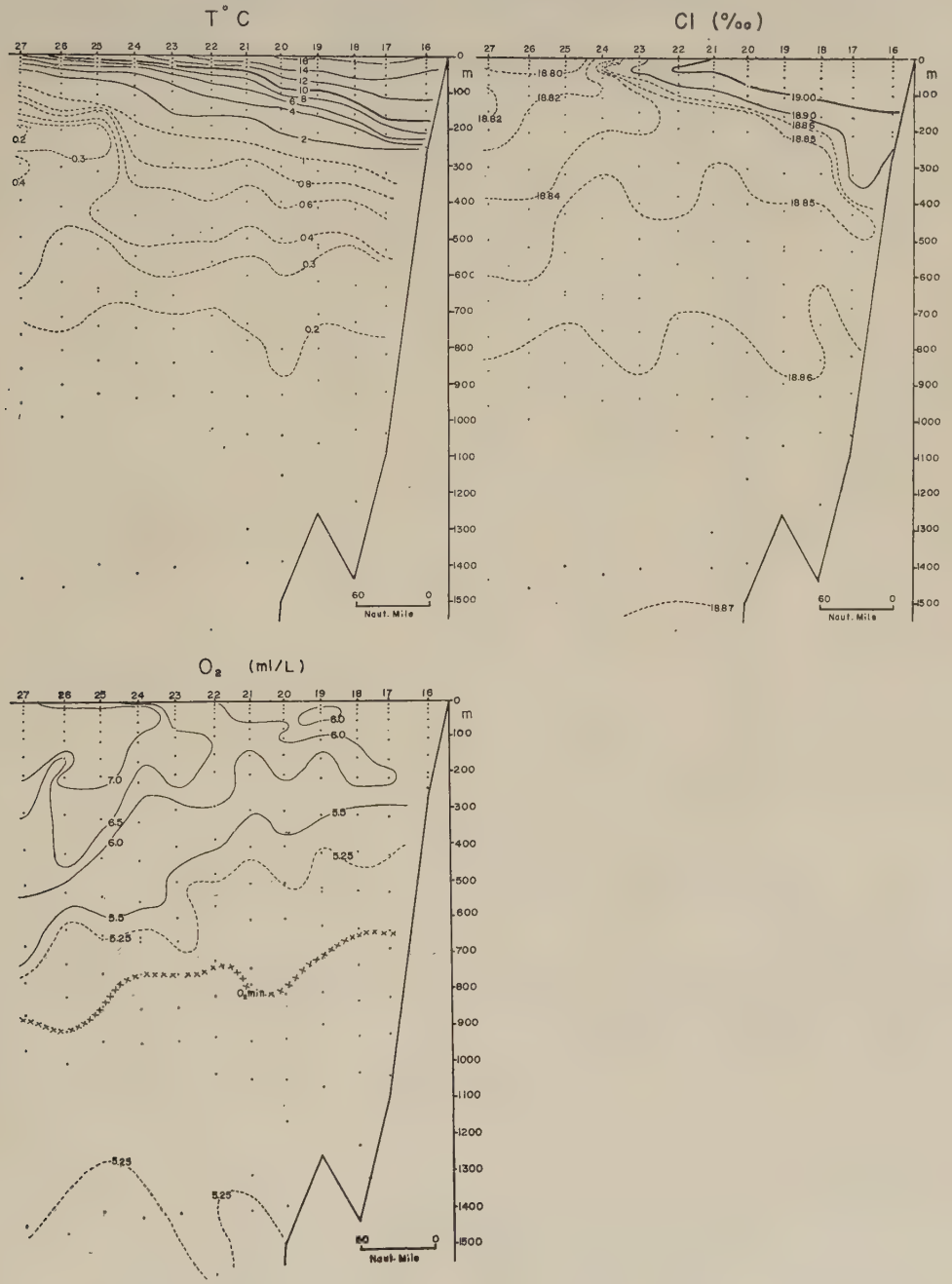

Fig. 7. Vertical sections of temperature in degrees centigrade (T°C), chlorinity in parts per mille (Cl ‰), dissolved oxygen in milli-liters per liter ($O_2 ml/L$).

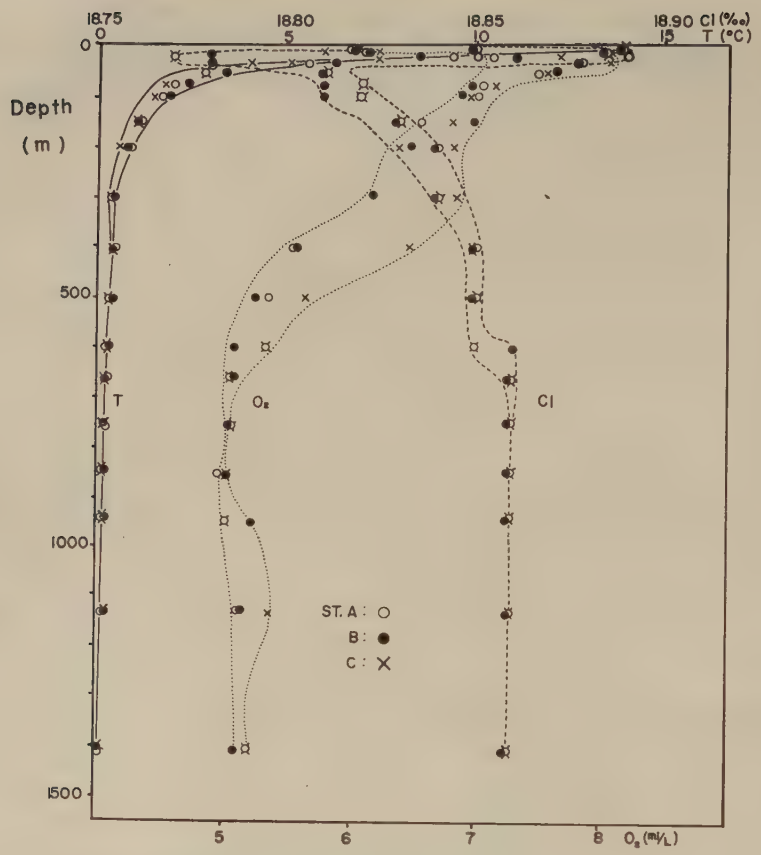

Fig. 8. Vertical distributions of temperature, chlorinity and dissolved oxygen at stations A, B and C.

Japan Sea sinks below the upper warm water and it makes the deep homogeneous water. The float observation supports the above speculation which expects the southward flowing deep current.

It is better to take the depth of no motion to be 700 m or more deeper than 400 m.

6. *Conclusion*

The float observation shows the deep current with a speed of 1.5 cm·sec^{-1} towards 235° true and the inertia motion.

Acknowledgments: The authors wish to express their sincere appreciation for the cooperation of member of observation and the crew on board the R/V Seifu-

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On the Circulation in the East China Sea and the Yellow Sea in Winter (Preliminary Report)

By

Osamu Asaoka *Nagasaki Marine Observatory*
Shigeo Moriyasu *Meteorological Research Institute*

(Received November 9, 1966)

Abstract: In winter of 1963, the southward extension of the cold water was very remarkable in the western part of the East China Sea and the warm water reached the head of the Yellow Sea. This feature is derived from the distribution of plankton diatoms as well. And then, a strong anticlockwise circulation is deduced. It is shown that NW wind can develop the anticlockwise circulation with the submarine topography and the development of the circulation in winter of 1963 is attributed to the effect of the monsoon which was extraordinarily strong.

1. *Introduction*

In Japan, they had very low air temperature and heavy snow-fall from December, 1962 to February, 1963. And sea surface temperature was also abnormally low in the sea around Japan. Kikuchi (1964) and Otsuka (1964) reported on the low water temperature in the East China Sea and the Yellow Sea. They concluded that one of the possible causes was the strong monsoon.

In this note, characteristic features in winter of 1963 are described on the distribution of sea surface temperature and of plankton diatoms in the region. And a circulation is deduced from them and its possibility is examined on the basis of a simple model.

2. *The distribution of sea surface temperature in winter of 1963*

One of the characteristic features in winter is a southward extension of cold water in the western part of the East China Sea and the Yellow Sea according to the report of Nagasaki Marine Observatory (1964). In winter of 1963, the feature was very remarkable. The distribution of sea surface temperature for the second tenday of February of 1963 is shown as a representative example in Fig. 1. The cold water extended southward in the western part, while the warm water reached north in the eastern part. Now, let us notice the length of 10°C

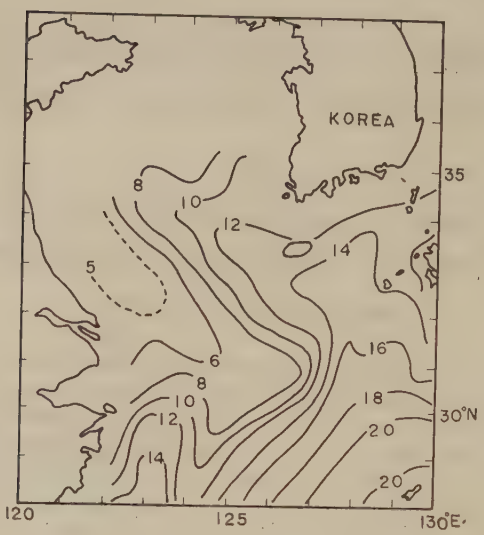

Fig. 1. Sea surface temperature (°C) in the second tenday of February, 1963 (from the Ten-day Marine Report of the East China Sea, published by the Nagasaki Marine Observatory).

Table 1. The length of 10°C isotherm at the surface in the direction from NW to SE in the second tenday of February (L) and the mean wind speed at Tomie from January to February (W).

Year	L*	W
1953	180 km	4.35 m/sec
1954	310	4.20
1955	310	4.35
1956	270	4.90
1957	330	4.40
1958	300	4.25
1959	400	4.80
1960	300	4.30
1961	470	3.75
1962	340	3.90
1963	670	6.00**

* L is determined based on the Ten-day Marine Report of the East China Sea published by the Nagasaki Marine Observatory.
** at Fukue about 10 km from Tomie.

isotherm in the direction from NW to SE. The length for the second tenday of February is shown in Table 1. The value for 1963 is more than 500 km and the average from 1953 to 1963 is about 350 km. This means that northward and southward flows were very predominant in the eastern and the western parts, respectively in winter of 1963.

According to KIKUCHI and OTSUKA, large negative deviation of sea surface temperature was found in the most part, while small negative or positive deviation was found in the northern part in the winter. From such a distribution of the deviation, they conclude that the warm water reached north. They point out an abnormal southward extension of the cold water in the western part.

Though we have no data on currents in the region, the existence of an anticlockwise circulation is expected from above considerations on sea surface temperature. Here, it is assumed that there are no significant differences in the distribution of external factors such as evaporation and radiation etc.

3. The distribution of plankton diatoms at the sea surface in winter of 1963

Water samples were obtained at the surface from February to March, 1963 and plankton organisms in 500 m*l* of sea water were condensed by settling and centrifuging.

Chaetoceros debilis CLEVE, a neritic and north temperate species (CUPP, 1943), appeared abundantly at two stations; the cell numbers of the specimens per liter of water were 10^6 and 10^5 at 30°N, 124°E and at 29°N, 126°E, respectively. We have made observations two or four times a year at the latter station since 1954, but *Chaetoceros debilis* has never been collected around the station. Such an abnormity of the phytoplankton calendar and large negative deviation of sea surface temperature at 29°N, 126°E suggest an existence of abnormal southward extension of the cold water north of the area (Fig. 2).

Moreover, *Rhizosolenia stolterfothii* H. PÉLAGALLO, an oceanic and warm-water species (CUPP, 1943), was distributed ubiquitously in the Kuroshio Current Region and the Tsushima Current Region (nearly along 128°E), and the sea surface temperatures were above 20°C and 15°C, respectively. Besides, in the north-western part of the Yellow Sea (35°N, 121°E), we found a remarkable phenomenon about the planktological conditions of this species. Namely, the sea surface temperature in the area was below 5°C and this low temperature affects mortally the life of the warm-water species. However, 280 cells/*l* of the specimens appeared there and most of the specimens seemed to be living from the

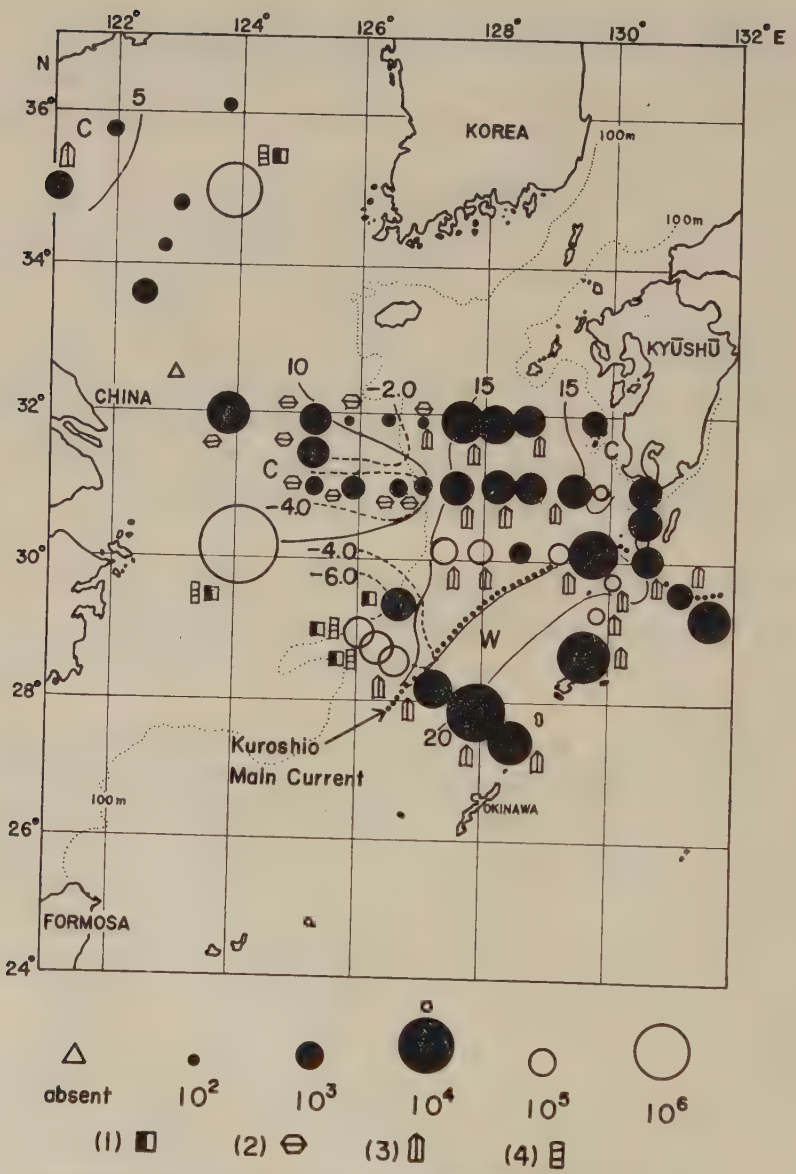

Fig. 2. Horizontal distribution of the total number of diatoms (cells/l) and the important species in the surface in the winter of 1963. Full line: sea surface temperature (°C); broken line: deviation of sea surface temperature from five year mean (1953–1957). Symbols of diatom species: (1) *Chaetoceros debilis*, (2) *Melosira sulcata*, (3) *Rhizosolenia stolterfothii*, (4) *Skeletonema costatum*.

fact that numerous chromatophores were found in the cells. The characteristic feature in the distribution of this species indicates that the warm water to the west of Kyushu reached rapidly the north-western part of the Yellow Sea. The rapid extension of the warm water probably caused smaller negative deviations of the sea surface temperature (−1°∼0°C) as compared with the deviations in the East China Sea.

Melosira sulcata Ehrenberg, a neritic and tychopelagic species (Cupp, 1943), is found with dense floating silt only in the bottom layer in the warm period, while in all layers in the cold period, and more, in general the species and floating silt appear in a limited sea area (30°∼32°N, 124°∼127°E) throughout all seasons. Accordingly, it is deduced that the area is occupied by a planktological water mass which is little mixed with surrounding waters.

From the planktological conditions mentioned above, it seems there was a large anticlockwise circulation centered around this stagnant region and that it was developed especially in winter of 1963 when NW wind was extraordinarily strong.

4. Discussion

In the preceding sections, it is deduced that there was an anticlockwise circulation in the East China Sea and the Yellow Sea and that the circulation was developed in winter of 1963. They say that the Tsushima Current flows northward in the sea west of Kyushu and that its branch exists in the eastern part of the Yellow Sea. The Yellow Sea is considered to be closed at the northern end and there must be a southward transport equal to the amount of the inflow due to the Tsushima Current. In other words, it is natural that an anticlockwise circulation is formed in the region. The abnormal development of the circulation in winter of 1963 seems to be related with NW wind and now the influence of the wind is discussed.

The region north of about 34°N is taken and a rectangular bay is considered. The x-axis points eastward, and the y-axis northward. The mouth of the bay is at $y=0$, and the shores are at $x=0$, $x=a$ and $y=b$. If the components of the wind stress at the sea surface are T_x and T_y and the stress vanishes at the bottom, the vertically integrated steady-state equations of motion are written in the form

$$-fV=-gh\frac{\partial\zeta}{\partial x}+T_x-RU$$

$$fU=-gh\frac{\partial\zeta}{\partial y}+T_y-RV.$$

Here, U and V are the x- and the y-components of volume transport from the surface to the bottom, ζ is the elevation of the sea surface, h is the depth to the bottom and R is the coefficient of friction. f is the Coriolis parameter and g is the acceralation of gravity. The equation of continuity is

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}=0.$$

A stream function ψ is introduced by the relations

$$U=\frac{\partial\psi}{\partial y},\quad V=-\frac{\partial\psi}{\partial x}.$$

If ζ is eliminated from the equations of motion and ψ is used, we obtain

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}-\left(\frac{1}{h}\frac{\partial h}{\partial x}+\frac{1}{h}\frac{f}{R}\frac{\partial h}{\partial y}\right)\frac{\partial\psi}{\partial x}+\left(\frac{1}{h}\frac{f}{R}\frac{\partial h}{\partial x}-\frac{1}{h}\frac{\partial h}{\partial y}\right)\frac{\partial\psi}{\partial y}$$
$$+\frac{1}{R}\left(\frac{\partial T_y}{\partial x}-\frac{\partial T_x}{\partial y}-\frac{T_y}{h}\frac{\partial h}{\partial x}+\frac{T_x}{h}\frac{\partial h}{\partial y}\right)=0.$$

We have no data enough to see the horizontal distribution of wind stress over the sea, and T_x and T_y are taken independent of x and y. If $\frac{1}{h}\frac{\partial h}{\partial x}$ and $\frac{1}{h}\frac{\partial h}{\partial y}$ are constant, the equation is of constant coefficients. The boundary conditions are given as follows:

$$\psi(0,\ y)=\psi(a,\ y)=\psi(x,\ b)=0$$
$$\psi(x,\ 0)=F(x).$$

Then, the solution is

$$\psi=\sum_{m=1}^{\infty}C_m\frac{e^{k_m y}-e^{k_m(2b-y)}}{1-e^{2k_m b}}e^{(\alpha x-\beta y)/2}\sin\frac{m\pi}{a}x$$
$$+\frac{2\gamma\pi}{a^2}\sum_{m=1}^{\infty}\frac{m\{1-(-1)^m e^{-\alpha a/2}\}}{\left(k_m^2-\frac{\beta^2}{a}\right)^2}\left\{e^{-(k_m-\beta/2)(b-y)}(1-e^{-2k_m y})+e^{-(k_m+\beta/2)y}-1\right\}\sin\frac{m\pi}{a}x,$$

where

$$\alpha=\frac{1}{h}\frac{\partial h}{\partial x}+\frac{f}{R}\frac{1}{h}\frac{\partial h}{\partial y},\quad \beta=\frac{f}{R}\frac{1}{h}\frac{\partial h}{\partial x}-\frac{1}{h}\frac{\partial h}{\partial y},\quad \gamma=\frac{1}{R}\left(\frac{T_y}{h}\frac{\partial h}{\partial x}-\frac{T_x}{h}\frac{\partial h}{\partial y}\right),$$
$$k_m^2=\left(\frac{m\pi}{a}\right)^2+\frac{1}{4}(\alpha^2+\beta^2),\quad e^{-\alpha x/2}F(x)=\sum_{m=1}^{\infty}C_m\sin\frac{m\pi}{a}x.$$

The first term of the right-hand side depends on the boundary condition at the mouth. If a and b have the order of 10^7cm and α and β have nearly the same order, the variation with y is approximately

$$e^{-(k_m+\beta/2)y} - e^{-2k_m b-(k_m-\beta/2)y}$$

(the latter is very small in comparison with the former) and the term decreases markedly with the distance from the mouth. The second term is due to the wind stress. The magnitude of this term is zero at the mouth ($y=0$), has a maximum at a distance from the mouth and vanishes at the head ($y=b$). This term represents a closed circulation and positive (negative) value of γ gives a clockwise (anticlockwise) circulation. If the magnitudes of gradient of h and of the wind stress are $\frac{\partial h}{\partial n}$ and T, respectively and the angle measured from the gradient of h to the wind stress is θ,

$$\gamma=\frac{1}{Rh}\frac{\partial h}{\partial n}T\sin\theta$$

is led. Therefore, the circulation is clockwise for $0<\theta<\pi$ and anticlockwise for $\pi<\theta<2\pi$. The outline of the flow pattern is noted above and its detail changes with constants included in ψ. This suggests that arbitrary patterns will be obtained by selection of the constants and the condition at the mouth.

The slope of the bottom in the Yellow Sea is much larger in the eastern part than in the western part. Therefore, it is assumed as the first approximation that the gradient of the depth to the bottom is in the direction from west to east and that its magnitude is represented by the function taken above. Then, for NW wind, an anticlockwise circulation is brought about by the effect of wind stress and the volume transport is proportional to the magnitude of wind stress. The boundary condition at the mouth can be given in various forms. If an inflow and an outflow are given in the eastern and the western parts, respectively, and the circulation caused by NW wind is taken into account an expected flow pattern is obtained, that is, the warm water flows northward in the eastern part, turns to west and then flows southward in the western part. The boundary condition taken above is based on the feature that there is an inflow of warm water branched from the Tsushima Current in the eastern part.

The volume transport due to wind stress is proportional to wind stress and it is significant to notice wind velocity. We have no data on wind velocity for the region and take wind velocity at Tomie (located at 32°37′N, 128°46′E) as an indicator. The most frequent direction and average speed in January and February are NW and 4.5 m/sec from 1953 to 1963, respectively. The wind speed for the period of 1963 is 6.0 m/sec and extraordinarily large (Table 1). Wind speed over the sea is considered to be larger than that at Tomie and it is ex-

pected that the wind speed over the sea in that period is above the critical value (6.6 m/sec) given by MUNK (1947). Thus, it is deduced that for 1963 the wind stress is much larger as compared with stress for other years and that the anticlockwise circulation was developed remarkably. The mean current speed from the surface to the bottom is dependent on the value of f/R. For $f/R=25$ and $\frac{1}{h}\frac{\partial h}{\partial n}=4.5\times10^{-8}$/cm, it is about 8 cm/sec in the eastern part for $T_y=-1$ dyne/cm^2 (nearly corresponding to the wind velocity of NW 7 m/sec). As we have no data, it can not be examined whether the values of current speed and of f/R are reasonable or not. The angle θ is another factor which is related to the volume transport. But, if winter is considered, θ is constant and its effect is not touched here.

The stagnant water region mentioned in Section 3 is not included in the model. But the existence of the region is deduced from the following consideration. In the western part, there is an extension of the southward flow derived in the model and in the eastern part, there is the Tsushima Current flowing northward. And, probably, a stagnant region exist between them and is located in the center of the anticlockwise circulation.

5. *Concluding remarks*

In winter of 1963, NW wind was very strong and the northward flow of warm water was remarkable in the eastern part of the Yellow Sea and the southward flow of cold water was also remarkable in the western part of the East China Sea and the Yellow Sea. Those results are based on the distribution of sea surface temperature and of plankton diatoms. The flow pattern for the Yellow Sea can be produced by a combination of the submarine topography and the wind stress, and the development of the circulation for winter of 1963 can be attributed to the abnormally strong monsoon. The flow pattern in the East China Sea is deduced in connection with the pattern in the Yellow Sea.

The lack of data obstructs the examination of the results, but this note will serve as the first step for studying the circulation in the region involving the East China Sea and the Yellow Sea.

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On the Distribution of *in situ* pH in the Adjacent Seas of Japan

By

Tsutomu Akiyama, Takeshi Sagi, Takeshi Yura and Kan Kimura

Japan Meteorological Agency

(Received November 16, 1966)

Abstract: The pH value at the surface ranges from 8.08 in the northern cold water to 8.40 in the southern warm water. The pH maximum occurs at the depth of 50 m, and the minimum at the depths of 1000–1200 m except the Japan Sea. Correlation coefficients between pH and the water temperature are 0.97, 0.81 and 0.48 respectively in the regions south and east of Japan, and in the Japan Sea. In the waters above the depth of 500 m, the pH value is a little higher in winter than in summer, but in the water deeper than 500 m a significant difference is not found in the pH values in both seasons.

1. *Introduction*

In the present study, authors intend to observe the general distribution of pH in the waters neighboring Japan in the winter (January-March) and the summer (July-September) of 1964.

A pH meter (Model HM-5A, manufactured by the Tōa-Denpa Kōgyo Co.) with a glass electrode was used for the present work. The measured values were converted to the *in situ* values according to the method of Strickland and Parsons (1960).

2. *General features of the vertical profile*

Fig. 1 indicates that there is a pH maximum in the upper layers, which can be clearly found in summer. The maximum (pH about 8.35) occurred at the depth of 50 m in the seas south and east of Japan. The minimum value (pH about 7.75) was found at the depths of 1000—1200 m which nearly coincides with the depth of oxygen minimum. In the Japan Sea the maximum value (pH about 8.25) was found at the depth of 50 m, but the minimum was not clear. From the vertical distributions of pH in the east of Japan (Fig. 1—A), and in the

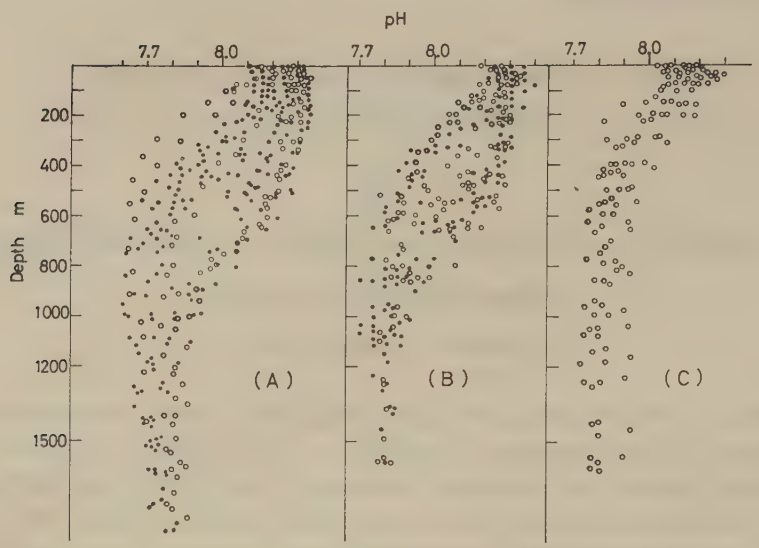

Fig. 1. Vertical profile of pH, 1964; open circles represent the values in summer, and closed circles in winter.
(A) the sea east of Japan (B) the sea south of Japan (C) the Japan Sea

south of Japan (Fig. 1—B), the pH values are divided into two groups according to the difference in pH value at the same depth. And a group of higher values is found within the Kuroshio axis and the south of it, while another group of lower values is found in the Oyashio water as shown in Fig. 1—A and in the coastal water as shown in Fig. 1—B. In the Japan Sea, the higher values seem to correspond to the southern warm water and the lower to the northern cold water (Fig. 1—C). However, we only have a small number of data for the Japan Sea, and the general trend should be confirmed by much more data in near future.

3. General features of the horizontal distribution

The horizontal distributions of pH in winter and summer at standard depths (0, 100, 500, and 1000 m) are shown in Figs. 2—6. The observed sea area can be divided into some representative water masses as shown in Table 1, according to the characteristic distributions of pH or other elements, such as chlorinity at the surface (Fig. 7) and surface current measured with GEK (Fig. 8). An average value of pH and water temperature of each water mass is given in Table 1.

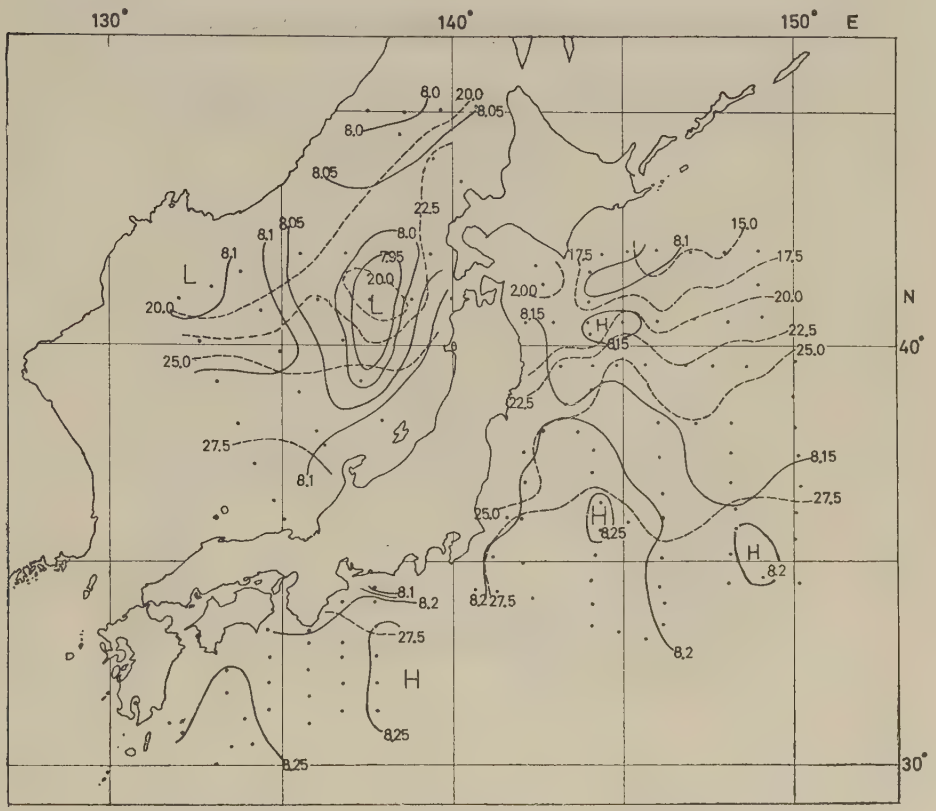

Fig. 2. Horizontal distribution at the surface in summer, 1964. Solid line: pH value, Broken line: water temperature in °C.

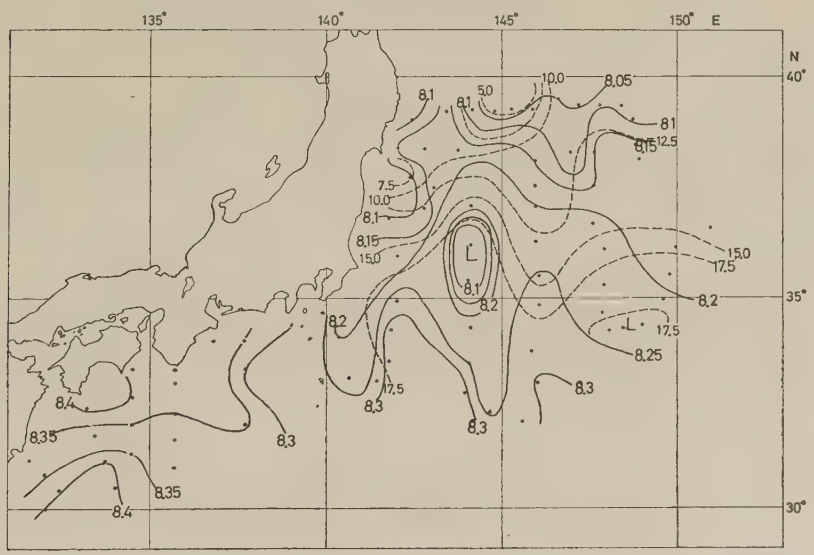

Fig. 3. Horizontal distribution at the surface in winter, 1964. Solid line: pH value, Broken line: water temperature in °C.

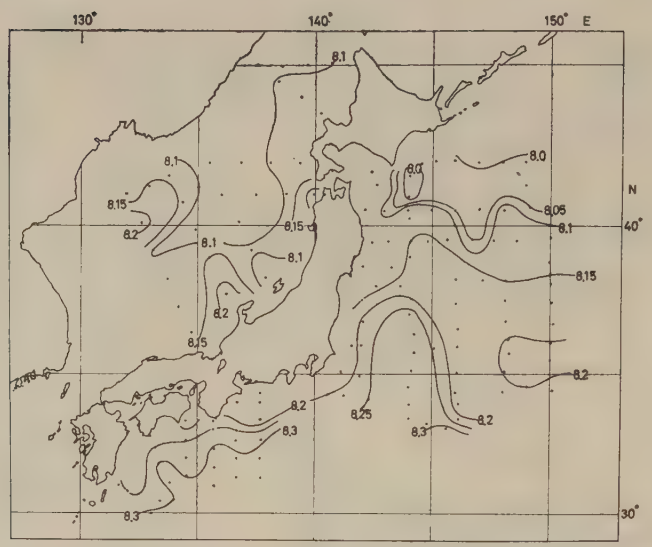

Fig. 4. Horizontal distribution of pH values in summer, 1964, at the depth of 100 m.

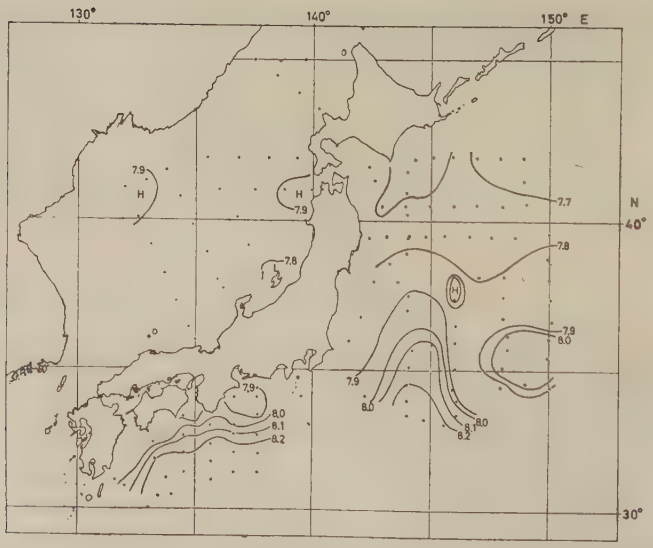

Fig. 5. Horizontal distribution of pH values in summer, 1964, at the depth of 500 m.

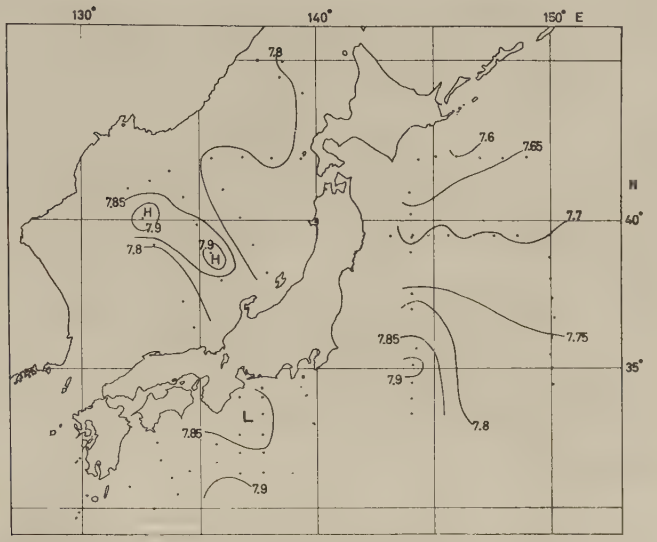

Fig. 6. Horizontal distribution of pH values in summer, 1964, at the depth of 1000 m.

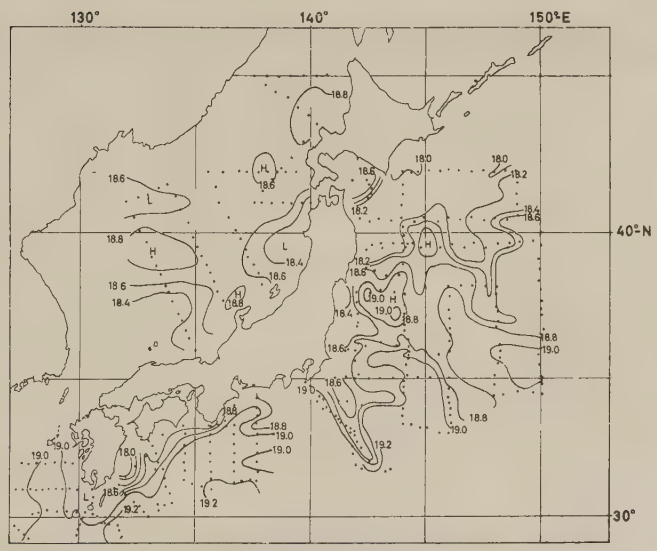

Fig. 7. Horizontal distribution of chlorinity in $^{0}/_{00}$ at the surface in summer, 1964.

Fig. 8. Surface currents measured with GEK in summer, 1964.

Table 1. Average pH value and temperature of each water mass at the surface.

		Winter		Summer	
		Temp.	*in situ* pH	Temp.	*in situ* pH
Western North Pacific Central Water	(130–140°E)	18–20°C	8.35	27–29°C	8.24
〃	(140–145°E)	18–20	8.26	27–29	8.22
〃	(145–150°E)	18	8.21	27–28	8.18
Kuroshio water	(130–140°E)	20	8.35	28	8.24
〃	(140–145°E)	18–20	8.30	28	8.23
〃	(145–150°E)	17–18	8.24	27–28	8.17
Oyashio water		<5	<8.0	<15	<8.1
Transitional water between Kuroshio and Oyashio water		5–15	8.0–8.2	15–27	8.1–8.2
Coastal water south of Japan		17–18	8.35	26–28	8.1–8.2
Coastal water east of Japan		10–15	8.1–8.2	17–27	8.15
Japan Sea	Tsushima Current Water	—	—	25–28	8.05–8.18
	Northern cold water	—	—	17–18	8.00

From the pH distribution in the surface layer, we can point out the following results: The highest value is generally found in the Kuroshio water and the lowest in the northern cold water in the Japan Sea. The pH value of the Kuroshio water gradually decreases towards the north along the course of the Kuroshio. In the transitional region between the Kuroshio water and the Oyashio

water which is situated in the sea east of Japan, the pH values occupy the middle value of those in the both water masses. In the Japan Sea, the water carried by the Tsushima Current (Tsushima Current Water), has relatively higher pH values than those in the northern cold water. The remarkable low value of pH was located at about 41°N, 138°E. In general, the pH value is fairly lower in the Japan Sea than in the Pacific Ocean as far as the same depth are concerned. The pH value is higher in winter by 0.05—0.1 than that in summer.

In the Kuroshio water and in the Japan Sea, the pH values at the depth of 100 m are higher about 0.05 than those at the surface, while in the Oyashio water, they are lower by 0.05—0.1 than those at the surface. The pH value at the depth of 500 m are a little lower than those at the surface in the Kuroshio water, while in the Oyashio water, coastal water of southern Japan and in the Japan Sea, they are much lower (pH about 0.2—0.3) at the depth of 500 m than those at the surface. The pH value at the depth of 1000 m are about 7.8 in the Kuroshio water and the Japan Sea, and about 7.6 in the Oyashio water.

4. Correlation between the pH and the water temperature

Table 2 shows correlation coefficients between pH and the water temperature in several sea areas in winter and summer. The correlation between the pH

Table 2. Correlation between temperature and pH. In A column, all the data of temperature observed were available and in B column, temperature ranged from 2° to 18°C.

season \ sea area		the sea south of Japan	the sea east of Japan	the Japan Sea
A	Winter	0.97	0.81	—
	Summer	0.71	0.79	0.48
B	Winter	0.98	0.81	—
	Summer	0.97	0.83	0.18

and the water temperature, as far as the waters with the temperature ranging from 2 to 18°C are concerned, are more significant except the Japan Sea. In the Japan Sea, there seems to be no significant correlation between the pH and the water temperature.

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Distribution of Plankton Collected on Board the Research Vessels of J. M. A. in 1965 (CSK)

By

Yutaka Kawarada *Japan Meteorological Agency*
Masataka Kitou *Japan Meteorological Agency*
Kenzo Furuhashi *Japan Meteorological Agency*
Akira Sano *Japan Meteorological Agency*
Kohei Karohji *Hakodate Marine Observatory*
Kazunori Kuroda *Kobe Marine Observatory*
Osamu Asaoka *Nagasaki Marine Observatory*
Masao Matsuzaki *Nagasaki Marine Observatory*
Mamoru Ohwada *Maizuru Marine Observatory*
Futomi Ogawa *Maizuru Marine Observatory*

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1. *Introduction*

The present studies are made in order to observe the distributional patterns of surface microplankton and macroplankton in the surface layer in the waters surrounding Japan. The materials were obtained on the cruises of Ryofu Maru of the Japan Meteorological Agency, Kofu Maru of the Hakodate Marine Observatory, Shumpu Maru of the Kobe Marine Observatory, Chofu Maru of the Nagasaki Marine Observatory and Seifu Maru of the Maizuru Marine Observatory, those which participated in the Cooperative Study of the Kuroshio and Adjacent Regions (CSK) starting from the summer of 1965.

As for the microplankton, samples were collected in the winter (January-March) and the summer (July-September) covering the neighboring waters of Japan, and in the spring (May-June) and the autumn (October-November) in the sea east of Japan, the Okhotsk Sea and the Japan Sea. Macroplankton samples, however, were collected in summer only in the waters surrounding Japan.

A systematic planktological investigation in the waters neighboring Japan has been continued since 1954 as a project of the Japan Meteorological Agency, Tokyo, in cooperation with its four district marine observatories. In these in-

vestigations, both the sampling method and the laboratory procedure of the microplankton and the processing macroplankton sample are just the same as mentioned in the next chapter. However, the collections of macroplankton had been made only by vertical hauls of the O-net which is explained in the next chapter with 100 m of wire out until 1964. The quantitative data on the microplankton chiefly on diatoms and on the macroplankton chiefly on copepods and chaetognaths collected on these investigations are presented in Results of Marine Meteorological and Oceanographical Observations No. 14-34 (1955-1965). The brief reports on the distribution of plankton are also shown in The Oceanographical Report of the Central Meteorological Observatory vol. 4-5 (1955-1956), The Oceanographical Report of the Japan Meteorological Agency vol. 5-7 (1956-1958) and The Results of Marine Meteorological and Oceanographical Observations No. 23-34 (1959-1965).

2. *Sampling method and laboratory procedure*

For collecting the surface microplankton and processing the materials in the laboratory for the purpose of accurate quantitative studies, the standard method which is detailed by MARUMO (1954) was employed. More than 500 m*l* of the surface water are dipped with a bucket and preserved after adding neutralized formalin liquid. In the laboratory, after the organisms in just 500 m*l* of sample water have been settled, sample water is reduced to about 15 m*l* by decanting by means of carefully siphoning, and the microorganisms settled near the bottom are condensed into a few drops of water by adopting the centrifugal force. The organisms obtained are removed on the graduated glass under the microscope, and their cell number is counted with species separately. In reporting the data amount of organisms is expressed as cell number per one liter of water.

As for the macroplankton, the two types of plankton nets were used in collecting samples; one is O-net and the other is NORPAC net. The former which is the standard net of the Japan Meteorological Agency, has a truncated conical head piece made of canvas, and measures 25 cm in length along the side of the head piece and 100 cm along the side of the bolting cloth GG54, 0.33 mm ×0.33 mm mesh apertures; the diameter of the trunk ring is 60 cm and the mouth opening is 36 cm in diameter. This net was towed vertically with 100 m of wire out at each station in the Okhotsk Sea, northern area of the sea east of Japan, south of Japan and the East China Sea. The latter is the North Pacific

Standard Net which measures 45 cm in mouth diameter and 180 cm in length along the side, being conical in shape; it is made of bolting cloth GG54, 0.33 mm × 0.33 mm mesh apertures. Samplings were made by 150 m approximately vertical hauls with the NORPAC net in the east of Japan and the Japan Sea. To estimate the strained water through the mesh of the net a flow-meter was mounted at the center of the mouth ring of each net. The depth to which the net reached was estimated by the wire angle, and the sample was preserved by adding neutralized formalin liquid. In the laboratory, the sample was split into two subsamples by the Folsom plankton sample splitter; the half of the sample was used for the wet weight measurement after removal of the water on the surface of the organisms by rolling them on the blotting paper, and the other half was used to count the number of individuals of chaetognaths with species separately on the graduated glass under the microscope. In reporting the data, amount of organisms and wet weight of total catch of macroplankton are expressed as number per one cubic meter of water.

3. Distribution of surface microplankton

(1) Winter (January-March, 1965)

(a) Standing crops of diatoms (Fig. 1)

The extremely large population of diatoms, being more than 10^4 cells per liter of water, was found in the water situated along the edge of the continental shelf in the East China Sea and in the Kuroshio Water* as well as in the coastal water in the south and east of Japan. In addition to these areas the central part of the Japan Sea was also densely populated with diatoms, amounting about 10^4 cells.

On the contrary, the small population of diatoms, less than 10^3 cells, appeared in the Western North Pacific Central Water, the Liman Current Water** in the Japan Sea and the shallow water over the continental shelf in the East China Sea. The paucity of diatoms was conspicuous in the far offshore part of Japan.

* The term Kuroshio Water in the present paper designates the water carried by the Kuroshio. As the Kuroshio follows closely along the coast of Japan in latitudes 30°N to 35°N, the Kuroshio Water appears to be mixing water of both coastal waters near Japan and the Western North Pacific Central Water defined by SVERDRUP *et al.* (1942).

** The term Liman Current Water in the present paper designates the cold water on the west side of the Japan Sea, which must have formed in the Japan Sea by excessive cooling in winter and must have been diluted by river water (SVERDRUP *et al.*, 1942).

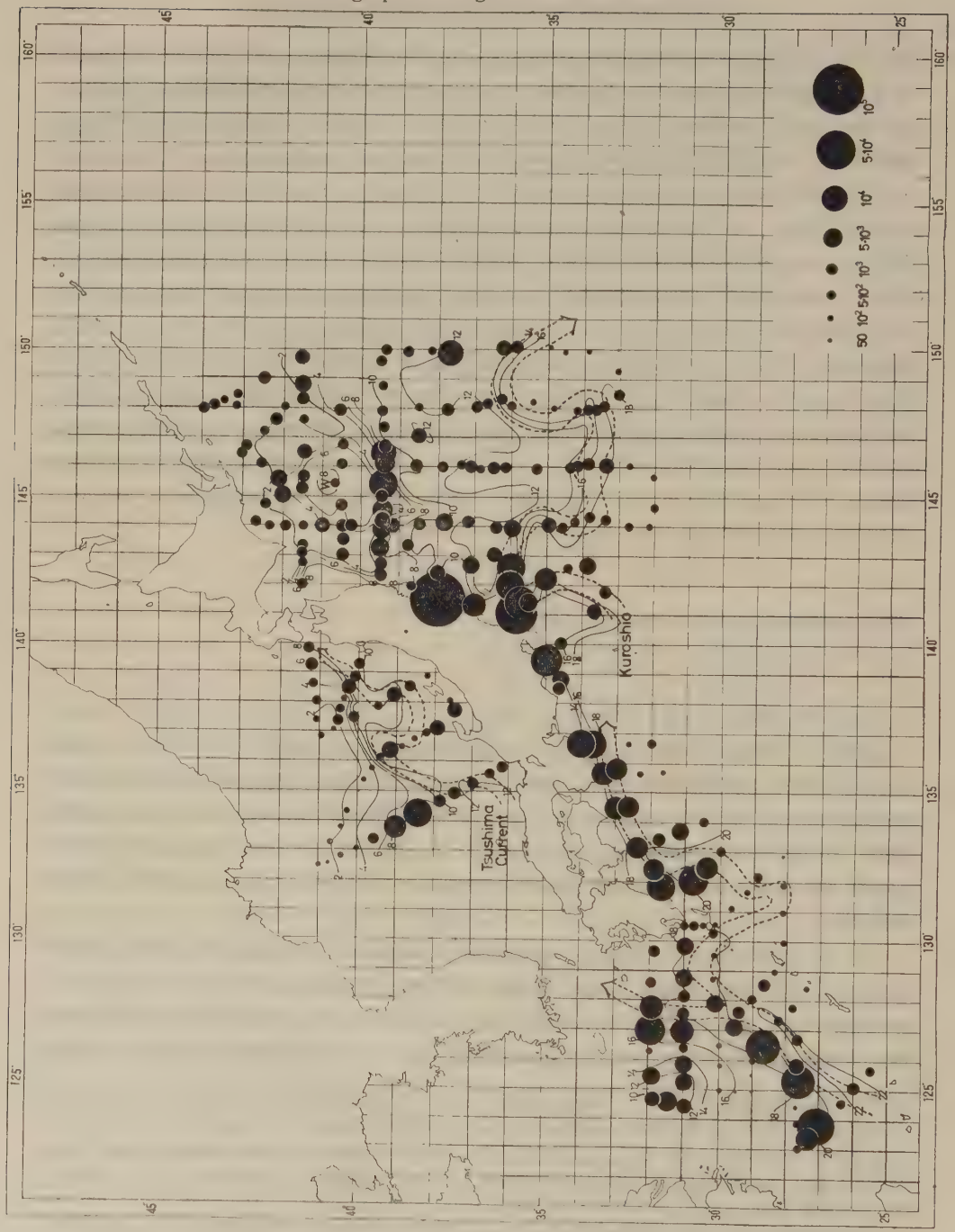

Fig. 1. Distribution of diatom standing crops (cells/l) and the temperature (°C) at the surface neighboring Japan from January to March 1965.

The moderate population of diatoms, ranging from 10^3 to 10^4 cells, was observed in the various water masses neighboring Japan; the Kuroshio Water, the cold water and the coastal water in the East China Sea, the Kuroshio Water east of longitude 144°E, the Oyashio Water, the Transition Water between the Kuroshio and the Oyashio Water in the east of Japan, the Tsushima Current Water and the coastal water in the Japan Sea.

The Kuroshio Water in the East China Sea was populated with diatoms in moderate number, being $5 \cdot 10^2$ to $5 \cdot 10^3$ cells, as previously mentioned, whereas in the south of Japan the population density of diatoms in the Kuroshio Water increased in amount of values 10 times ($5 \cdot 10^3 - 5 \cdot 10^4$) higher than those in the East China Sea. This large population of diatoms in the Kuroshio Water was held in the coastal region of the sea east of Japan, and then it began decreasing, where the Kuroshio turned east in latitude 34°N, particularly in the east of longitude 144°E, being in the same order ($5 \cdot 10^2 - 5 \cdot 10^3$) of that in the East China Sea. Such geographical variations of the population density of diatoms in the Kuroshio Water were due to the course of the Kuroshio; as the Kuroshio in the south and east of Japan flowed closely to the coast of Japan, the Kuroshio Water was much influenced by the coastal water with the extremely dense population of diatoms, being more than 10^4 cells, and therefore the Kuroshio Water along the coast of Japan was densely populated with diatoms.

(b) Diatom communities (Fig. 2)

The diatom communities mainly composed of the warm water species, such as *Bacteriastrum comosum*, *B. elongatum*, *B. hyalinum*, *B. minus*, *B. varians*, *Chaetoceros affinis*, *C. brevis*, *C. costatus*, *C. curvisetus*, *C. distans*, *C. messanensis*, *C. lorenzianus*, *C. pseudocurvisetus*, *Eucampia zoodiacus*, *Guinardia flaccida*, *Lauderia borealis* and *Rhizosolenia stolterfothii*, with the neritic species as *Nitzschia longissima*, *N. seriata*, were found in the Kuroshio Water, the Western North Pacific Central Water and the Tsushima Current Water.* However, the amounts of the each diatom species occurring in these water masses were different from one another.

In the Kuroshio Water, the geographical variations of the diatom communities were observed as in the population density: In the East China Sea, the

* The Tsushima Current, a branch of the Kuroshio, enters the Japan Sea following the western coast of Japan to the north. The term Tsushima Current Water in the present paper designates the water of high temperature and high salinity carried by the Tsushima Current, and it occupies considerably large sea area between the Tsushima Current and the coast of Japan.

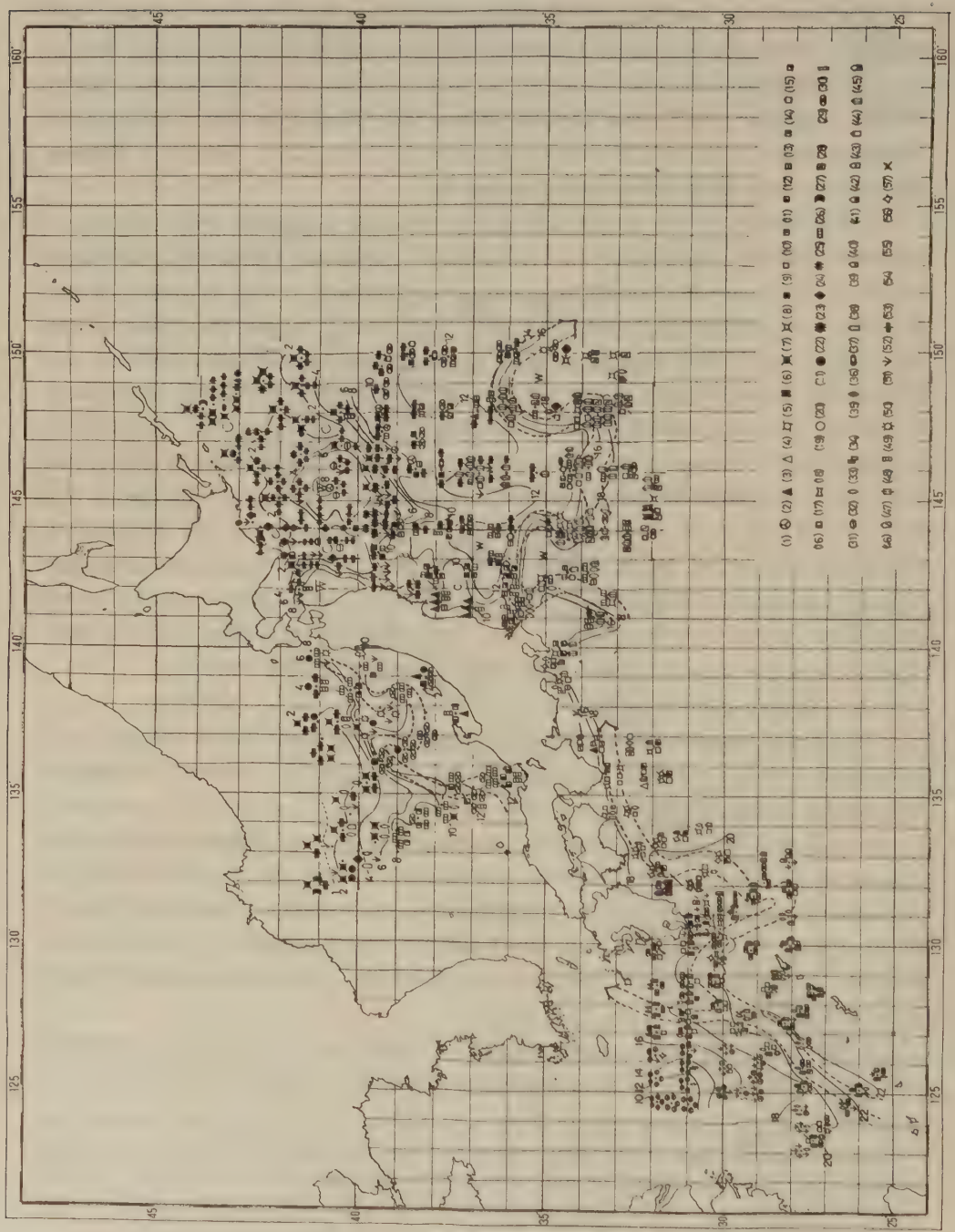

Fig. 2. Distribution of diatom communities and the temperature (°C) at the surface neighboring Japan from January to March 1965. Symbolized figures represent the important diatom species. Each figure approximately corresponds to 20 per cent of total diatoms in occurrence. Specific names represented by the figures are given:
(1) *Actinoptychus undulatus*, (2) *Asterionella japonica*, (3) *Asterionella notata*, (4) *Bacteriastrum comosum*, *B. delicatulum*, *B. elongatum*, *B. hyalinum*, *B. mediterraneum*, *B. minus*, *B. varians*, (5) *Cerataulina bergoni*, (6) *Chaetoceros atlanticus*, *C. concavicornis*, *C. convolutus*, (7) *Chaetoceros atlanticus* v. *neapolitana*, *C. atl.* v. *skeleton*, *C. denticulatus*, (8) *Chaetoceros compressus*, *C. constrictus*, *C. debilis*, *C. decipiens*, *C. furcellatus*, *C. radicans*, *C. socialis*, (9) *Chaetoceros affinis*, *C. brevis*, *C. costatus*, *C. curvisetus*, *C. distans*, *C. lorenzianus*, *C. messanensis*, *C. pseudocurvisetus*, (10) *Chaetoceros decipiens*, (11) *Chaetoceros compressus*, (12) *Chaetoceros curvisetus*, (13) *Chaetoceros debilis*, (14) *Chaetoceros didymus*, (15) *Chaetoceros radicans*, (16) *Chaetoceros socialis*, (17) *Climacodium biconcavum*, (19) *Coscinodiscus lineatus*, *C. radiatus*, (21) *Coscinodiscus* spp., (22) *Coscinosira polychorda*, (23) *Dactyliosolen mediterraneus*, (24) *Denticula seminae*, (25) *Eucampia cornuta*, *E. zoodiacus*, (26) *Fragilaria* spp., (27) *Guinardia flaccida*, (29) *Lauderia borealis*, (30) *Leptocylindrus danicus*, (31) *Melosira sulcata*, (32) *Nitzschia closterium*, *N. delicatissima*, *N. longissima*, *N. seriata*, *N.* spp., (33) *Nitzschia paradoxa*, (35) *Pleurosigma* spp., (36) *Pseudoeunotia doliolus*, (37) *Rhizosolenia alata* f. *gracillima*, *R. styliformis*, (39) *Rhizosolenia calcar avis*, (41) *Rhizosolenia hebetata* f. *semispina*, (42) *Rhizosolenia imbricata* f. *shrubsolei*, (43) *Rhizosolenia setigera*, (44) *Rhizosolenia stolterfothii*, (45) *Rhizosolenia styliformis* v. *latissima*, (46) *Rhizosolenia styliformis* v. *longispina*, (47) *Schröderella delicatula*, (48) *Skeletonema costatum*, (49) *Stephanopyxis palmeriana*, (51) *Thalassionema nitzschioides*, (52) *Thalassiosira decipiens*, *T. nordenskiöldii*, *T.* sp., (56) Pennatae misc., (57) absent.

main components of the diatom communities were *Laud. borealis*, *Nitz.* spp. and *Rh. stolterfothii*, and in addition to these species, the warm water species of subgenus *Hyalochaete*, *Euc. zoodiacus* and *Thalassionema nitzschioides* were also present in considerable number. Whereas in the south of Japan, *Laud. borealis* and *Euc. zoodiacus* remarkably decreased in occurrence, and the main components here became genus *Bact.* and subgenus *Hyal.*, those which were almost absent or considerably small in number in the previous sea area. Together with these species, genus *Nitz.*, *Rh. stolterfothii* and *Schröderella delicatula* were present as the second components of the communities. In the east of Japan, however, *Rh. stolterfothii* prevailed as in the East China Sea and subgenus *Hyal.* was also predominant in occurrence as in the south of Japan. The second components of the diatom communities here, were rich in species number compared with the other two areas; they were genus *Bact.*, *Ch. decipiens*, *Ch. radicans*, *Guin. flaccida*, *Laud. borealis*, *Nitz. seriata*, *Skeletonema costatum* and *Stephanopyxis palmeriana*.

As the diatom communities in the Kuroshio Water showed close resemblance with those in the Western North Pacific Central Water, it seemed that there may be no difference in nature between the two water masses, but the population density of diatoms was remarkably different from each other, as previously mentioned. It is supposed from the richness in diatom population that the Kuroshio Water may be much influenced by the coastal water near Japan.

In the Tsushima Current Water in the Japan Sea, the diatom communities were characterized by the predominant occurrence of *Laud. borealis* and *Euc. zoodiacus*, and by the remarkable decrease in occurrence of the other warm water species, being prevalent in the East China Sea and the Pacific side of Japan. Among them, the paucity of *Rh. stolterfothii* which was the most important form of the diatom communities in the Pacific side of Japan including the East China Sea was conspicuous. From such a difference in the diatom communities between the Pacific side of Japan and the Japan Sea, it is supposed that the Tsushima Current Water may have not so distinct character of warm water mass as the Kuroshio Water in the winter.

A branch of the Tsushima Current flows out to the Pacific side through the Tsugaru Straits as the Tsugaru Current. The population density of diatoms in the Tsugaru Current Water was fairly large, as in the Tsushima Current Water, being 10^3. The diatom communities, however, were different from those in the Tsushima Current Water. Instead of the warm water species, being prevalent in the Tsushima Current Water, the neritic and cold water forms, such as *Sk. costatum*, *Th'ma nitzschioides* and *Thalassiosira* spp., were the main components of the diatom communities.

The diatom communities of the densely populated region with diatoms situated along the edge of the continental shelf in the East China Sea were characterized by the predominant occurrence of the warm water species, such as *Chaetoceros brevis*, *C. curvisetus*, *C. messanensis*, *C. pseudocurvisetus* and *Rh. stolterfothii*, and in addition, *Nitz.* spp., *Euc. zoodiacus*, *Laud. borealis* and *Schröd. delicatula* were present. As such diatom communities were closely resembled to those of the Kuroshio Water, the water of the dense diatom population may be reflected the character of the Kuroshio Water.

In the Oyashio Water, the main components of the diatom communities were *Chaetoceros atlanticus*, *C. concavicornis*, *C. convolutus*, *Coscinosira polychorda*, *Denticula seminae*, *Th'ra decipiens* and *Th'ra* spp., and in addition, the cold water species of subgenus *Hyal.* (*C. compresuss*, *C. constrictus*, *C. debilis*, *C.*

decipiens, *C. furcellatus*, *C. radicans*), *Fragilaria* spp. and *Melosira sulcata* were present in relatively small number. The similar diatom communities as in the Oyashio Water, were found in the Liman Current Water, being in the offshore part of the Japan Sea. The surface water temperature of the Liman Current Water ranged from 1° to 6°C as in the Oyashio Water. Thus, the closely resembled properties between the Liman Current and the Oyashio Water were recognized, but the population density of diatoms was different from each other. The total diatom population of the Liman Current Water was less than $5 \cdot 10^2$ cells per liter of water, while in the Oyashio Water it ranged from 10^3 to $5 \cdot 10^3$. It is supposed from the above-mentioned facts that the Liman Current Water may reflect the oceanic nature, *i. e.*, it may be not so influenced by the coastal waters or other water masses as the Oyashio Water.

Besides the Oyashio and the Liman Current Water, the water of low surface temperature, ranging from 10° to 14°C, was observed over the continental shelf in the East China Sea. The diatom communities in this cold water were characterized by the monotonous occurrence of *Mel. sulcata*. According to the vertical mixing of the water over the continental shelf in winter, the tychopelagic form, as *Mel. sulcata* appeared in large number in the surface from the bottom. Accordingly, the cold water in the East China Sea may be different in nature from the Oyashio and the Liman Current Water.

The other water mass of surface temperatures of 14° to 18°C was found over the continental shelf in the East China Sea, and was characterized by the paucity of diatoms and the occurrence of the neritic species, such as *Actinoptychus undulatus*, *Nitz.* spp. and *Th'ma nitzschioides*. As those properties of this water mass are different from those of the above-mentioned cold water and the densely populated water with diatoms situated along the edge of the continental shelf, this water mass may have special character.

The Transition Region between the Kuroshio and the Oyashio Water was situated between lat. 36° and 39°N in the east of Japan, being 6° to 14°C in surface temperature. The diatom communities here were characterized by the mixing associations of the warm and cold water forms; the main components were *Ch. curvisetus*, *Ch. didymus*, *Laud. borealis* and *Rh. stolterfothii* as the warm water forms, and *Ch. compressus*, *Ch. constrictus* *Ch. decipiens*, *Ch. radicans*, *Th'ra decipiens* and *Th'ra* sp. as the cold water forms. Together with these species, the neritic forms, such as *Act. undulatus*, *Asterionella japonica*, *Pseudoeunotia doliolus* and *Sk. costatum* were present in small number.

(2) *Summer (July-September, 1965)*

(a) Standing crops of diatoms (Fig. 3)

The densely populated regions with diatoms were remarkably decreased in area compared with those in the winter. The large population of diatoms, being more than 10^4 cells per liter of water, was found in the coastal regions of northern Japan and the Kurile Islands. Together with these regions, a restricted region near Taiwan and the central part of the East China Sea were also densely populated with diatoms. Besides these regions, the population density of diatoms in the waters neighboring Japan was fairly small, being mostly from 10^2 to 10^3.

In the Kuroshio Water in the East China Sea, the diatom populations (10^2 -10^3) were reduced to one-fifth of those in the winter. Similar decrease in amount of total diatoms was also found in the Kuroshio Water south of Japan, where the population density ranged from 10^3 to 10^4.

The paucity of diatoms was remarkable in the Western North Pacific Central Water, the northern waters of the East China Sea, the central water of the Japan Sea and the Okhotsk Sea.

(b) Diatom communities (Fig. 4)

The diatoms occurred in the summer were rich in species number compared with those in the winter, and particularly the various forms of the warm water species appeared.

The diatom communities in the Kuroshio Water, the Western North Pacific Central Water and the Tsushima Current Water were composed of the warm water species, such as *Ch. atlanticus* v. *neapolitana*, *Ch. coarctatus*, *Ch. dadayi*, *Ch. denticulatus*, *Ch. pendulus*, *Ch. pseudodichaeta*, *Ch. tetrastichon*, *Ch. affinis*, *Ch. curvisetus*, *Ch. didymus* v. *anglica*, *Ch. distans*, *Ch. lorenzianus*, *Ch. messanensis*, *Climacodium biconcavum*, *Clim. frauenfeldianum*, *Dactyliosolen mediterraneus*, *Guinardia flaccida*, *Hemiaulus hauckii*, *Leptocylindrus danicus*, *Rh. acuminata*, *Rh. alata*, *Rh. al.* f. *gracillima*, *Rh. bergonii*, *Rh. castracanei*, *Rh. cylindrus*, *Rh. styliformis*, *Rh. styl.* v. *latissima* and *Rh. styl.* v. *longispina*. There was no essential difference in diatom community between the Kuroshio Water and the Western North Pacific Central Water, but the population density of diatoms was different from each other as in the winter; the large population density in the Kuroshio Water showed that the Kuroshio Water was much influenced by the coastal water near Japan. The geographical variations of the

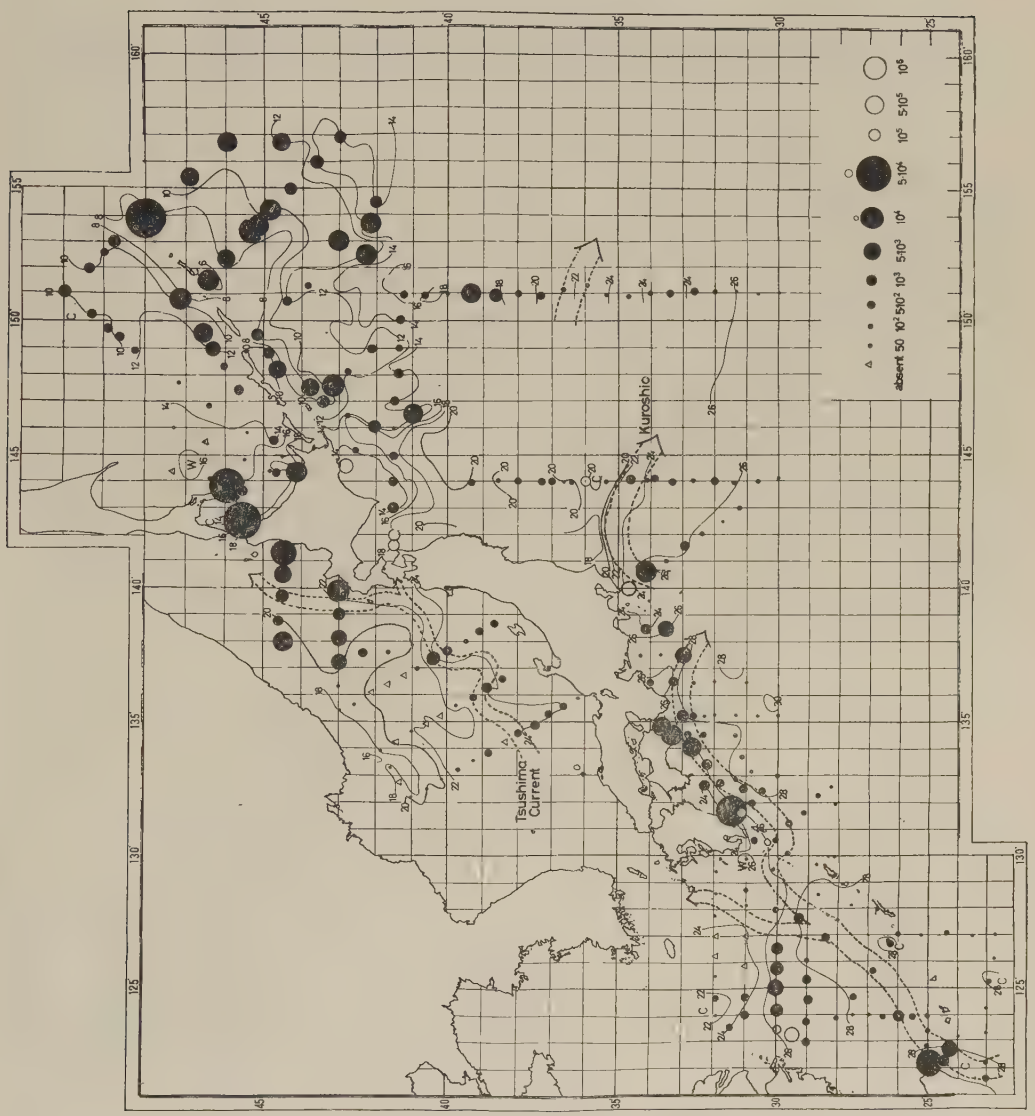

Fig. 3. Distribution of diatom standing crops (cells/l) and the temperature (°C) at the surface neighboring Japan from July to September 1965.

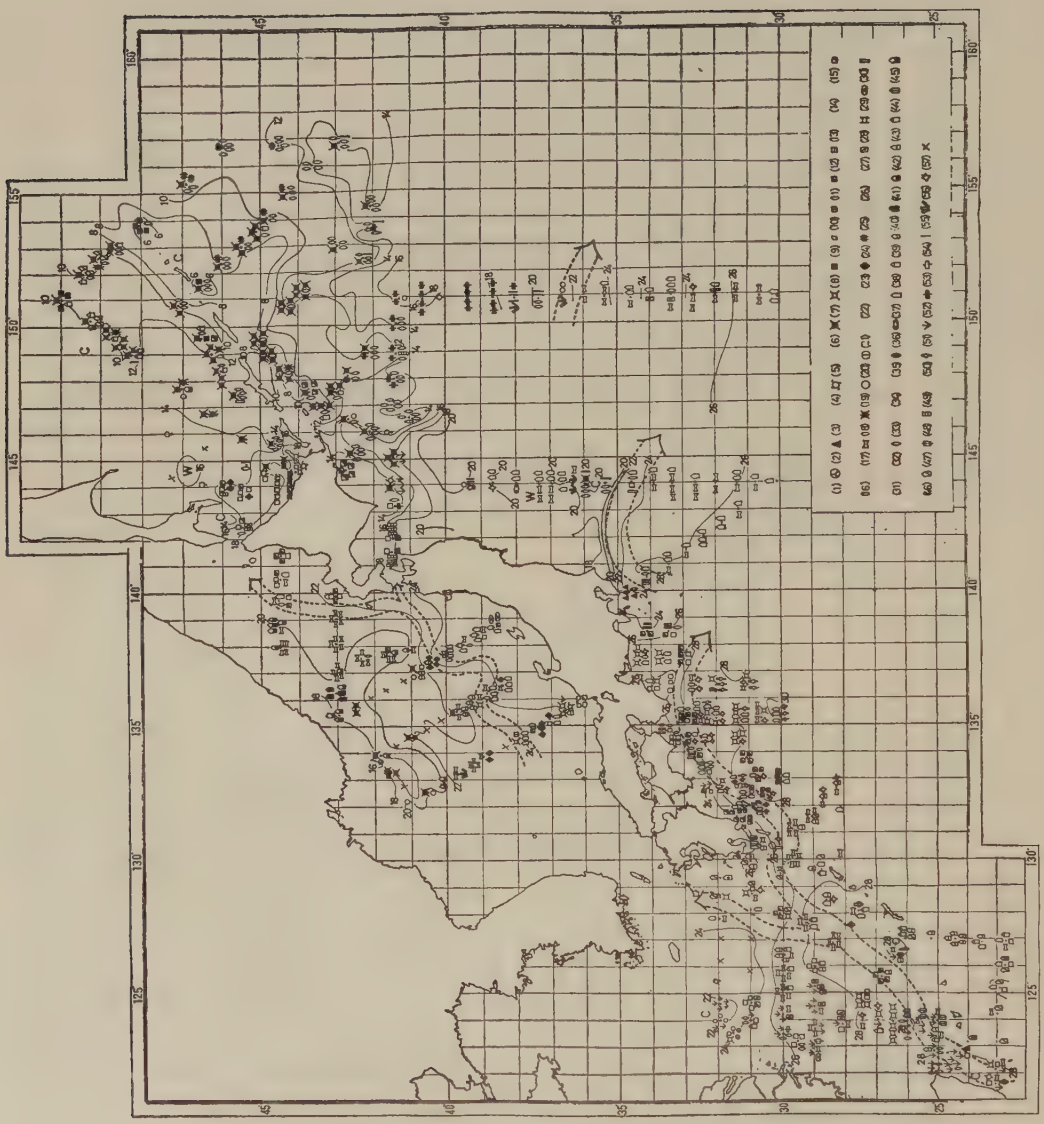

Fig. 4. Distribution of diatom communities and the temperature (C°) at the surface neighboring Japan from July to September 1965. Symbolized figures represent the important diatom species. Each figure approximately corresponds to 20 per cent of total diatoms in occurrence. Specific names represented by the figures are given:
(1) *Actinoptychus undulatus*, (2) *Asterionella japonica*, (4) *Bacteriastrum delicatulum*, *B. varians*, *B.* spp., (6) *Chaetoceros atlanticus*, *C. concavicornis*, *C. convolutus*, (7) *Chaetoceros atlanticus* v. *neapolitana*, *C. coarctatus*, *C. dadayi*, *C. danicus*, *C. denticulatus*, *C. pendulus*, *C. tetrastichon*, *C. pseudodichaeta*, (8) *Chaetoceros compressus*, *C. debilis*, *C. radicans*, (9) *Chaetoceros affinis*, *C. curvisetus*, *C. didymus*, *C. did.* v. *anglica*, *C. distans*, *C. diversus*, *C. laciniosus*, *C. lorenzianus*, *C. messanensis*, (10) *Chaetoceros decipiens*, (11) *Chaetoceros compressus*, (12) *C. lorenzianus*, (15) *Chaetoceros radicans*, (17) *Climacodium biconcavum*, *C. frauenfeldianum*, (18) *Corethron hystrix*, (19) *Coscinodiscus lineatus*, *C. radiatus*, (20) *Coscinodiscus rothii*, (23) *Dactyliosolen mediterraneus*, (24) *Denticula seminae*, (27) *Guinardia flaccida*, (28) *Hemiaulus hauckii*, *H. membranaceus*, (29) *Lauderia borealis*, (30) *Leptocylindrus danicus*, *L. minimus*, (32) *Nitzschia closterium*, *N. delicatissima*, *N. pacifica*, *N. seriata*, *N.* spp., (35) *Pleurosigma* spp., (36) *Pseudoeunotia doliolus*, (37) *Rhizosolenia acuminata*, *R. alata*, *R. al.* f. *gracillima*, *R. bergonii*, *R. calcar avis*, *R. castracanei*, *R. cylindrus*, *R. stolterfothii*, *R. styliformis*, *R. sty.* v. *longispina*, (38) *Rhizosolenia alata*, *R. al.* f. *gracillima*, (39) *Rhizosolenia calcar avis*, (40) *Rhizosolenia fragilissima*, (41) *Rhizosolenia hebetata* f. *semispina*, (42) *Rhizosolenia imbricata* f. *shrubsolei*, (43) *Rhizosolenia setigera*, (44) *Rhizosolenia stolterfothii*, (45) *Rhizosolenia styliformis* v. *latissima*, (46) *Rhizosolenia styliformis*, (47) *Schröderella delicatula*, (48) *Skeletonema costatum*, (50) *Stigmaphora rostrata*, (51) *Thalassionema nitzschioides*, (52) *Thalassiosira decipiens*, *T.* sp., (53) *Thalassiosira rotula*, (54) *Thalassiothrix delicatula*, *T. longissima*, *T. mediterranea* v. *pacifica*, (55) *Thalassiothrix frauenfeldii*, (56) Pennatae misc., (57) absent.

diatom communities in the Kuroshio Water were not so distinct as the population density.

In the Japan Sea, the surface temperature of the Tsushima Current Water was considerably lower, being 22° to 24°C, than that of the Kuroshio Water in the East China Sea, being 24° to 28°C, but the diatom communities as well as the diatom populations were similar each other. Therefore, the Tsushima Current Water in the summer seemed to reflect the properties of warm water mass as the Kuroshio Water, compared with the winter. In the Tsushima Current Water north from lat. 41°N, the population density was larger than that in the southern part, and *Ch. curvisetus* and *Ch. compressus* was predominant, instead of genus *Rhiz.* Two branches of the Tsushima Current were found in the summer; one was the Tsugaru Current and the other the Soya Current. The Tsugaru Current Water was characterized by the predominence of *Sk. costatum* and the dense population of the total diatoms, being about 10^5 cells per liter of water. In consequence, the Tsugaru Current Water seemed to be changed in

quality passing through the Tsugaru Straits, while in the Soya Current Water the planktological properties were nearly similar to those in the northern Tsushima Current Water.

The Oyashio Water of low surface water temperature, being from 6° to 16°C, was densely populated with diatoms, except the central part of the Okhotsk Sea where the total populations of diatoms were less than 10^2. The diatom communities here, were composed of the cold water forms, such as *Ch. atlanticus*, *Ch. concavicornis*, *Ch. convolutus*, *Ch. debilis*, *Ch. radicans*, *Corethron hystrix*, *Dent. seminae*, *Rh. alata* and *Rh. hebetata* f. *semispina*, and the neritic forms, such as *Nitz. closterium*, *Nitz. delicatissima*, *Nitz. seriata* and *Nitz. pacifica*. The species number of the cold water diatoms were remarkably decreased in occurrence compared with the winter.

The Liman Current Water was characterized by the paucity of diatoms, being less than 10^2 cells, and the occurrence of the cold water forms, such as *Ch. atlanticus*, *Ch. concavicornis*, *Rh. fragilissima* and *Rh. hebetata* f. *semispina*. Though the cold water forms of diatoms were present in both the Liman Current Water and the Oyashio Water, the population density of total diatoms was very small in the Liman Current Water in both winter and summer. Therefore, the Liman Current Water was seemed to reflect the oceanic nature as mentioned in the preceding chapter.

The diatom communities in the shallow water over the continental shelf were characterized by the predominant occurrence of *Th'ma nitzschioides*. Together with this species, *Ch. curvisetus*, *Ch. didymus*, *Ch. lorenzianus*, *Ch. messanensis*, *Clim. biconcavum*, *Clim. frauenfeldianum*, *Guin. flaccida*, *Rh. alata*, *Rh. al.* f. *gracillima* and *Rh. calcar avis* were also present in considerable number. The distributions of the diatom population as well as the diatom communities here in summer were different from those in winter.

4. Biomass of zooplankton

The biomass in terms of wet weight of the zooplankton sample at each station is shown in Fig. 5. At a glance of it, we can easily find that the biomass varies from place to place.

(1) The Pacific side

In the east of Taiwan, the biomass was small, being from 7 to 105 mg per one cubic meter of water and 39 mg in the mean.

Fig. 5. Distribution of zooplankton biomass (mg/m³ in wet weight) and the temperature at the 100 m depth neighboring Japan from July to September 1965.

In the south of Japan, the coastal water was densely populated with zooplankton, being in the range from 55 to 180 mg and 90 mg in the mean, compared with the Western North Pacific Central Water, being less than 74 mg and 34 mg in the average.

In the east of Japan, the biomass of the Oyashio Water was remarkably large, being from 68 to 725 mg and 290 mg in the mean. However, in the Western North Pacific Central Water, the biomass was extremely small in comparison with that of the Oyashio Water, being from 29 to 120 mg and 73 mg in the average. In the Transition Region between the Kuroshio and the Oyashio Water, the biomass was moderate in quantity, being from 29 to 250 mg and 110 mg in the average. In the Tsugaru Current Water, the biomass was 94 mg.

(2) The East China Sea

In the Kuroshio and the Tsushima Current Water, the biomass was small, being from 12 to 112 mg and 55 mg in the mean, while in the shallow water over the continental shelf, it became extremely large, being from 82 to 473 mg in the mean.

(3) The Japan Sea

In the Tsushima Current Water, the biomass was very small, being less than 59 mg and 40 mg in the mean, while in the Liman Current Water it was large, being in the range from 30 to 133 mg and 110 mg in the average.

(4) The Okhotsk Sea

The biomass in the Okhotsk Sea was fairly large, being from 86 to 302 mg and 180 mg in the mean.

5. *Distribution of chaetognaths in summer*

The following twenty-three species were identified. They were already known as the epiplanktonic or mesoplanktonic species in the seas around Japan.

Sagitta hexaptera d'Orbigny

S. lyra Krohn

S. scrippsae Alvariño

S. enflata Grassi

S. elegans Verrill

S. bipunctata Quoy et Gaimard

S. ferox Doncaster

S. robusta Doncaster

S. bedoti Béraneck
S. pulchra Doncaster
S. serratodentata pacifica Tokioka
S. serratodentata pseudoserratodentata Tokioka
S. regularis Aida
S. neglecta Aida
S. crassa Tokioka
S. crassa f. *naikaiensis* Tokioka
S. minima Grassi
S. decipiens Fowler
S. neodecipiens Tokioka
Pterosagitta draco (Krohn)
Eukrohnia hamata (Möbius)
Krohnitta subtilis (Grassi)
K. pacifica (Aida)

In order to find out important chaetognaths in the various water masses, the frequency of occurrence of all species was examined in the following water masses; the Western North Pacific Central Water near Taiwan, in the south of Japan and in the east of Japan, the coastal water in the south of Japan, the Transition Water between the Kuroshio and the Oyashio Water, the Oyashio Water, the Tsugaru Current Water, the Kuroshio Water, the shallow water over the continental shelf in the East China Sea, the Tsushima Current Water and the Liman Current Water in the Japan Sea, and the Okhotsk Sea Water. In consequence, sixteen species, except *S. bipunctata*, *S. robusta*, *S. pulchra*, *S. crassa*, *S. crassa* f. *naikaiensis*, *S. decipiens* and *S. neodecipiens*, were selected as the important chaetognaths whose frequency percentage in some water masses exceeded 50%.

The horizontal distributions of the standing crops of chaetognaths and the chaetognath communities are shown in Figs. 6 and 7, respectively.

(1) East of Taiwan

All stations were covered by the Western North Pacific Central Water. The population density was moderate, being 8.9 individuals per one cubic meter of water in the average, though the total number of chaetognaths at each station varied in the wide range from 2.6 to 25.0 inds. The chaetognath communities were poor in species because of the absence of *S. hexaptera*, *S. lyra*, *S. ser. pseudoserratodentata*, *K. subtilis*, *K. pacifica*, *S. bedoti* and *S. minima*, those

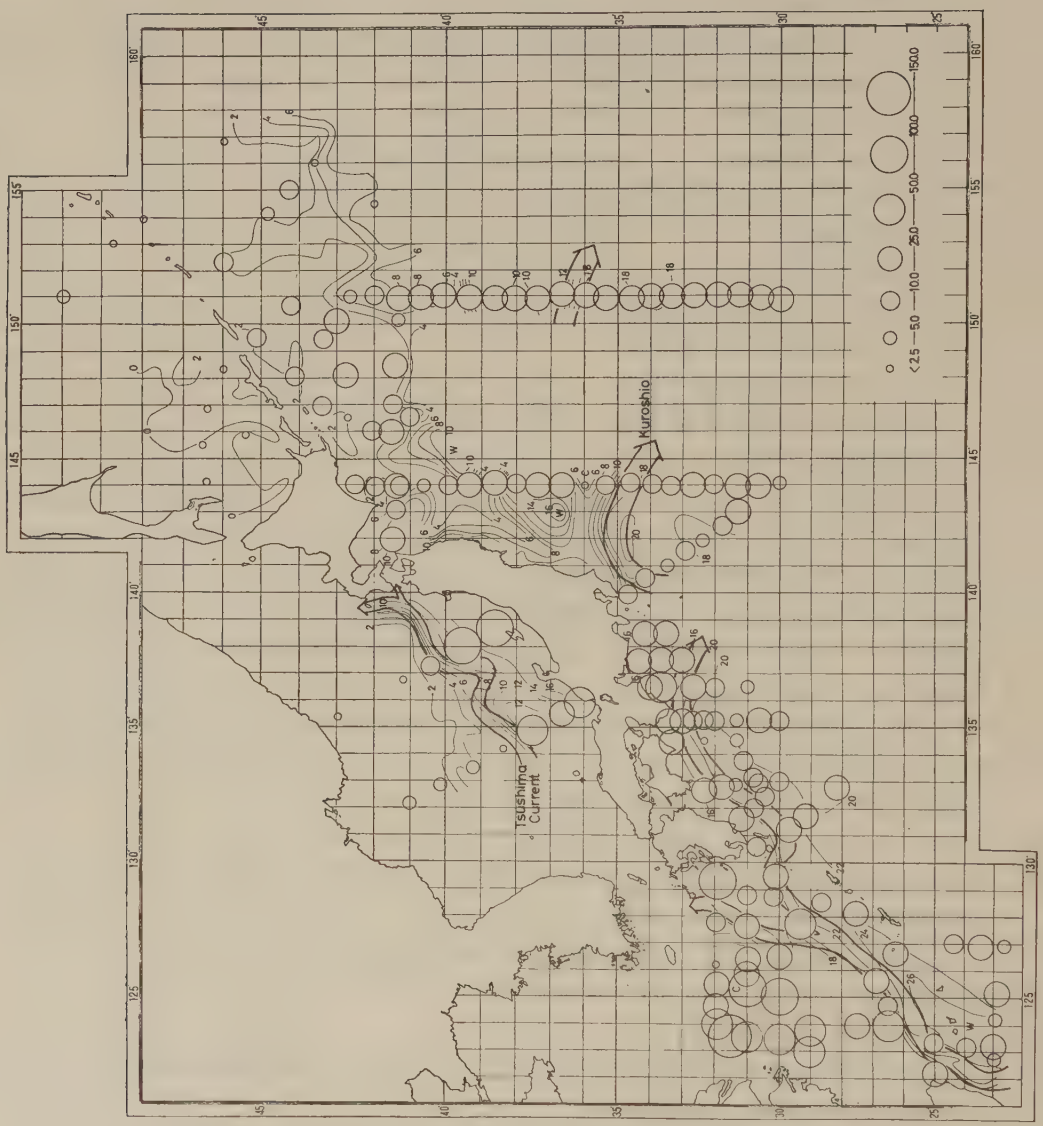

Fig. 6. Distribution of chaetognath standing crops (inds./m³) and the temperature at the 100 m depth neighboring Japan from July to September 1965.

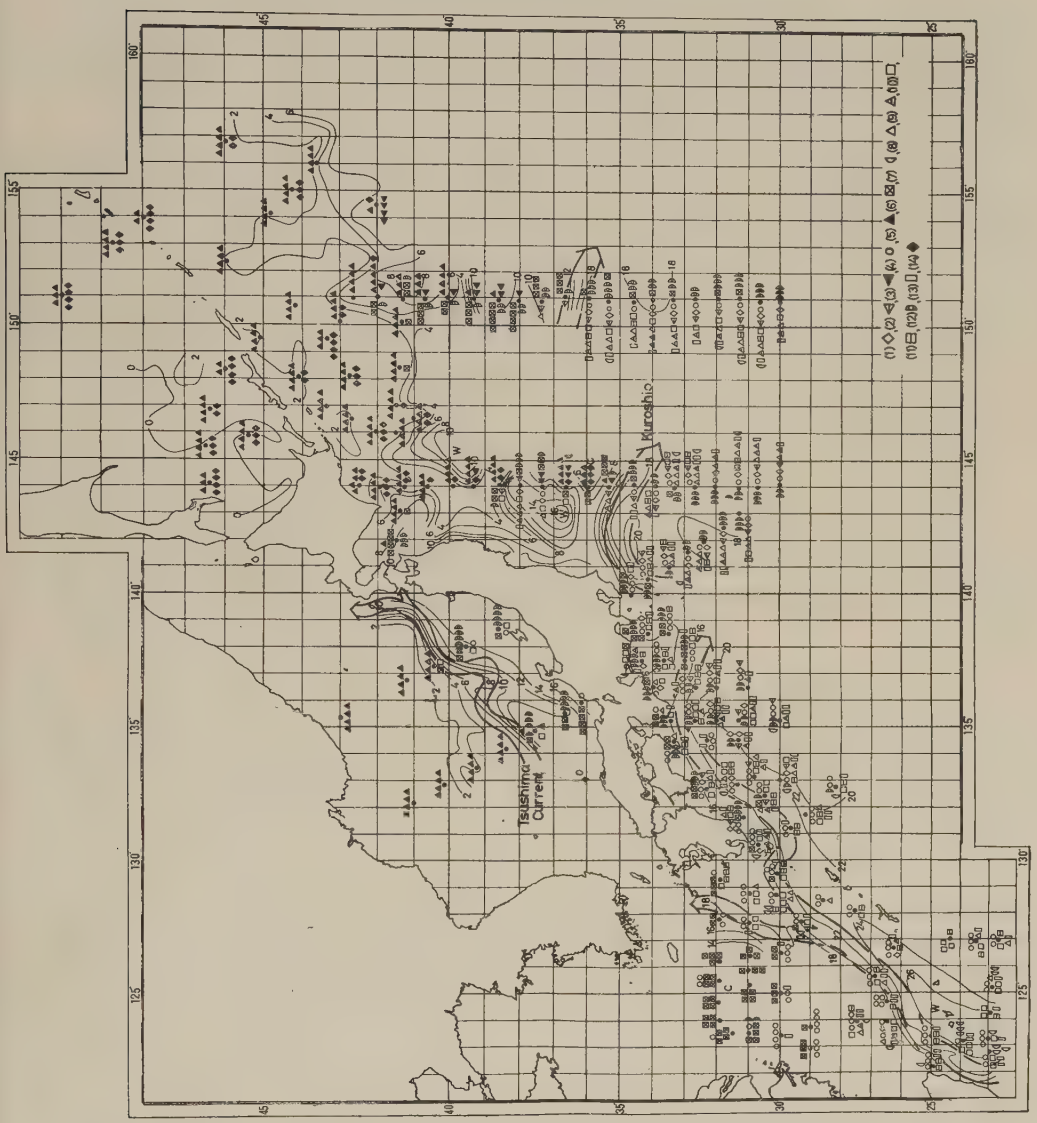

Fig. 7. Distribution of chaetognath communities and the temperature (°C) at the 100 m depth neighboring Japan from July to September 1965. Symbolized figures represent the important chaetognath species. Number of symbols in a station indicates the percentage of animals; below 10%, 10–25%, 25–50% and above 50% of total chaetognaths. Specific names represented by the figures are given:
(1) *Sagitta hexaptera*, (2) *S. lyra*, (3) *S. scrippsae*, (4) *S. enflata*, (5) *S. elegans*, (6) *S. bedoti*, (7) *S. ferox*, (8) *S. serratodentata pacifica*, (9) *S. serratodentata pseudoserratodentata*, (10) *S. regularis*, (11) *S. neglecta*, (12) *S. minima*, (13) *Pterosagitta draco*, (14) *Eukrohnia hamata*.

which were found frequently in the south and east of Japan. The main components here, were *S. enflata*, *S. ferox* and *S. regularis*, *P. draco* and *S. neglecta* became the second components.

(2) South of Japan

The Western North Pacific Central Water in the south off the Kuroshio, was populated with chaetognaths in moderate numbèr, being mostly from 5.1 to 25.0 inds. and 8.7 inds. in the average. Among many warm oceanic species found, *S. enflata* and *P. draco* were the main components, and *S. minima* and *S. regularis* were the second components. However, *S. minima* was scarce in the western part, and *S. enflata* occurred in small percentage in the southern part.

In the coastal region, the population increased in number, ranging from 10.1 to 25.0 inds. and 19.2 inds. in the average. The communities were mainly composed of *S. minima*, *S. enflata*, *S. bedoti* and *S. regularis*. This region was rich in warm oceanic forms under the influence of the Kuroshio Water, among which the neritic species, *S. bedoti*, was limited in the northern waters from the Kuroshio.

(3) East of Japan

In the Western North Pacific Central Water, the population density was moderate, being 10.8 inds. in the average, and it was somewhat larger along lat. 151°E than that in the waters west of lat. 145°E. The chaetognath communities here, were characterized by the richness in warm water species. Among them, the main component was *S. minima*, and the second components were *P. draco*, *S. ser. pacifica*, *S. ser. pseudoserratodentata* and *S. enflata*. It is noticeable that *S. bedoti* was distributed in the far south from the Kuroshio along lat. 151°E. From the results of the planktological surveys carried out by the Japan Meteorological Agency (1962-1965) in the east of Japan, the distribution of *S. bedoti* was usually restricted in the Transition Region between the Kuroshio and the Oyashio Water. Consequently, the water distributed by *S. bedoti* in the south of the Kuroshio seemed to be cut off by the Kuroshio from the Transition Region.

In the Oyashio Water of 100 m deep which was less than 5°C in temperature, the population density was moderate, being mostly from 5.1 to 25.0 inds. and 7.8 inds. in the average. The predominant species was *S. elegans*. *E. hamata* was also found to be prevalent though to a less extent. Together with these species, *S. scrippsae*, *S. bedoti*, *S. regularis* and *S. minima* were present, but they were limited in the southern edge of this waters.

In the Transition Region, the population density was relatively large, being 12.1 inds. in the average. This region was characterized by the abundant occurrence of *S. bedoti*. *S. minima* was also widely found but in small number. Several warm oceanic species, such as *S. hexaptera*, *S. enflata*, *S. ser. pacifica*, *S. ser. pseudoserratodentata*, *S. regularis* and *P. draco*, were found around the isolated warm eddy, but they were almost absent in the water of low temperature, less than 10°C at the depth of 100 m, while the cold water species, such as *S. elegans*, *E. hamata* and *S. scrippsae*, were dominant in the water of low temperature, ranging from 5° to 7°C at the 100 m depth and were absent in the water of relatively high temperature more than 10°C.

In the Tsugaru Current Water, the population of chaetognaths was 12.9 inds. *S. bedoti*, *S. minima* and *S. elegans* were found, among which the former two species prevailed.

(4) The Okhotsk Sea

The amount of total chaetognaths was small, being less than 2.5 inds. The chaetognath communities were composed of *S. elegans* and *E. hamata*, as in the northern Oyashio Water.

(5) The East China Sea

In the Kuroshio Water, the population density was large, being from mostly 5.1 to 50.0 inds. and 15.7 inds. in the average. *S. enflata* was the most important component of the chaetognath communities, and *S. neglecta*, *S. regularis* and *P. draco* were also present as the second components. Together with these species, small amounts of *S. hexaptera*, *S. lyra*, *S. ser. pacifica*, *S. ser. pseudoserratodentata* and *S. bedoti* were found, but *S. minima*, *K. subtilis* and *K. pacifica* were entirely absent. Such chaetognath communities were closely resembled those in the Western North Pacific Central Water east off Taiwan. The neritic species, *S. bedoti*, was distributed from the northern East China Sea to the waters near lat. 29°N.

In the shallow water over the continental shelf, the remarkably dense population of chaetognaths was observed. The mean number of total chaetognaths was 37.0 inds. and the maximum reached to 117.0 inds. There were two different chaetognath communities; one was characterized by the predominence of *S. enflata* and the other was by *S. bedoti*. The former community was found in the southern part influenced by the Kuroshio Water and the latter in the northern part influenced by the cold water originated from the Yellow Sea.

In the East China Sea, *S. minima* occurred at only one station, 31°00′N,

123°30'E. The remarkable decrease of *S. minima* here, compared with the waters in the south and east of Japan, was unaccountable.

(6) The Japan Sea

The population density in the Tsushima Current Water was remarkably large, being 50.6 inds. in the average. The warm water species, *S. minima*, was mostly predominant, and the warm oceanic species, such as *S. enflata*, *S. ser. pseudoserratodentata* and *S. regularis*, were also found but in small number. In addition to these species, *S. bedoti* was widely found, but the quantity was small.

In the Liman Current Water, *S. elegans* occurred monotonously but in small number. Another cold water species, *E. hamata*, which prevailed in the Oyashio Water and the Okhotsk Sea, was entirely absent in the Japan Sea. Therefore, the nature of water between the Oyashio and the Liman Current Water seemed to be different from each other.

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Verification of the Fourier Approximation of the Space-wise Interpolation of BT Data in the Pacific Ocean

By

Masao Hanzawa

Japan Meteorological Agency

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1. *Background*

Physical, as well as fisheries, oceanographers can benefit from the basic information derived from the distribution of sea water temperature at the surface and in the subsurface layers. The information is especially important to meteorologists for analysis of the air-sea energy exchange problems.

Sea surface temperatures of the oceans have been presented in both geographical and numerical forms since the early stages of modern oceanography. However, it is only since the development of the bathythermograph (BT) (Spilhaus, 1938) that it has been possible to prepare reliable charts of subsurface temperature differences in the layers between the surface and 122 m. (400 ft.), (Robinson, 1954, 1957).

Available BT data are erratically distributed in space and time, with most observations being concentrated along regular ships' tracks. Thus, ocean-wide subsurface temperature analyses must be based on a large amount of interpolation and extrapolation. This is extremely time consuming when done subjectively by hand. In order to minimize such time-consuming procedures, Robinson (1964) has developed computer programs to analyze available BT and reversing thermometer data.

The numerical analysis computes mean temperatures from the available data for unit areas 1° latitude by 1° longitude. A two-dimensional space interpolation is performed, using Laplace's equation. Observed and interpolated values are next smoothed in space along both latitude and longitude axes. The final step performs a Fourier harmonic analysis of the space-smoothed values with a truncated summation over three harmonics. This step smooths the data along

the time axis and provides the desired harmonic parameters.

This report is intended to verify the subsurface temperature model obtained from this computer analysis by comparing the results with hydrographic cast data taken in the same area but not used in the computer analysis. The comparisons show good agreement in the temperature-depth structure, in the amplitude and the phase of the seasonal cycle at the surface and the subsurface standard levels. Differences in means did not exceed limits of variance.

2. *Data*

2-1. *Hanzawa Sample*

During the years of 1949-1953, the Japan Meteorological Agency, then the Central Meteorological Observatory, Tokyo, carried out a series of detailed hydrographic observations on a north-south line from the Kii Peninsula, Honshu Island, down to Ocean Weather Station "TANGO" (29°N, 135°E). Hydrographic casts with conventional Nansen bottles and reversing thermometers were taken at close intervals in time and space. The line crosses the main axis of the Kuroshio, perpendicularly.

The total number of observations used in this analysis was 311. Observations were sorted into 1°×1° squares, and also into months. These squares were designated as Areas A, C, E, G, H, and I, respectively, by the Japan Meteorological Agency, as shown in Figure 1. The number of observations for each square varies according to month or locality, having a maximum of eight (8) in October, in Area C, and a minimum of one (1) in January, in Area G (Table I). The observations were usually clustered within 30 miles; however, in Areas H and I, the Ocean Weather Ship on some occasions was located within the adjacent 1° square to the west. All data were interpolated and read for standard depths of 0, 10, 25, 50, 75, 100, and 150 meters, and monthly means calculated.

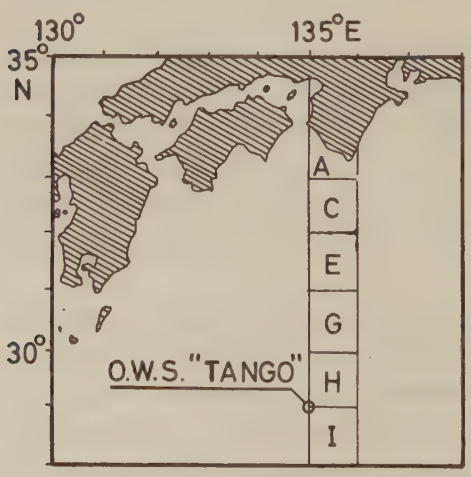

Fig. 1. "Area" designation chart.

TABLE I. Total Number of Hydrographic Cast (Central Meteorological Observatory, Tokyo) Observations by Months.

Area \ Month	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Area "A"	4	2	5	3	7	4	5	4	5	7	2	6	54
Area "C"	4	2	5	3	7	3	6	6	6	8	3	6	59
Area "E"	4	2	5	3	5	4	7	5	6	7	3	5	56
Area "G"	1	3	3	3	5	4	7	6	5	7	3	5	52
Area "H"	2	2	5	4	3	5	6	4	6	3	4	4	48
Area "I"	3	3	3	4	5	6	4	3	3	2	2	4	42
Total	18	14	26	20	32	26	35	28	31	34	17	30	311

The data were selected from the years 1949-1953. They were taken in all months, at all locations, and are of extremely high quality. While the area covered is limited to a single longitude, it extends across the highly variable Kuroshio Current. This is a good area for comparison with the computer analysis because, here, both seasonal temperature variation and within month variation is large, and both change appreciably with latitude.

2-2. Robinson Sample

The data for the selected areas were furnished by Margaret K. ROBINSON of the Scripps Institution of Oceanography, University of California, San Diego. A total of 677 observations were used (Table II). The data include 111 BT observations from various sources, with 566 additional hydrographic casts taken by the former Imperial Japanese Navy. The accuracy of individual BT observations may be very poor in error by as much as 3°C (5°F), but an attempt was made to screen out errors. Possible errors in the BT observations were minimized by combining them with the Japanese hydrographic cast data. The Japanese observations used were means calculated by the U. S. Navy Oceanographic Office from data collected prior to 1941 by the former Imperial Japanese Navy.

3. The Fourier Values

In this report, the comparisons are made between the Japanese hydrographic cast data (Hanzawa sample) and the Robinson data which has been smoothed mathematically by the computer, rather than with the American raw observed values. In order to get a complete space-time solution of temperature distribution at the surface and in the near-surface depths, a new method has been

TABLE II. Total Number of Bathythermograph (BT) and Japanese Hydrographic Cast (JH) Observations By Months

Lat.	Long.	Type of Obs.*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
33N (Area "A")	135E	BT	1954–1		1956–2	1946–1	1954–2 1956–1	1951–1 1954–3	1950–1	1945–1 1952–1 1953–1	1949–1 1953–1	1949–1 1953–1	1951–1 1954–1 1955–2 1956–2	1950–1	26
		JH	28	2	24	34		39	44					38	209
Totals—			29	2	26	35	3	43	45	3	2	2	6	39	235
32N (Area "C")	135E	BT	1954–2	1947–1	1954–2 1956–1	1946–1 1954–1	1954–1 1955–1 1956–1	1954–1	1950–1 1951–2	1952–1 1953–1 1954–1	1953–1	1945–1 1953–2 1954–1	1945–1 1953–2 1955–2 1956–3	1947–1	32
		JH		29	46		46				41				162
Totals—			2	30	49	2	49	1	3	3	42	4	8	1	194
31N (Area "E")	135E	BT	1954–2	1947–1 1954–2	1955–1 1956–2		1955–3 1956–1		1945–2 1951–1	1945–1 1954–1	1945–1	1945–1 1953–3 1954–1	1953–1 1955–2 1956–3		29
		JH			10	6		5	5				10	15	51
Totals—			2	3	13	6	4	5	8	2	1	5	16	15	80
30N (Area "G")	135E	BT	1953–2		1945–2	1951–1	1955–1		1951–1	1945–1 1949–1 1952–1 1953–1 1954–2	1945–1	1953–1	1952–2		17
		JH	2	2		6	11	7					9	4	41
Totals—			4	2	2	7	12	7	1	6	1	1	11	4	58
29N (Area "H")	135E	BT								1945–1 1952–1					2
		JH	7	8	4	7	5	6	3	10	4	8	10	8	80
Totals—			7	8	4	7	5	6	3	12	4	8	10	8	82
28N (Area "I")	135E	BT			1954–1	1954–2			1964–1	1945–1					23 5
		JH	1	6			1	4	1	8	1			1	23
Totals—			1	6	1	2	1	4	2	9	1			1	28
													Grand Total.....		677

*BT figures include 26 Japanese BTs.

developed by ROBINSON (1964). Detailed explanation of this method is given in her report; only a brief description is stated here.

A two-dimensional space-interpolation scheme, based on a solution of Laplace's equation provides approximate values for every 1° square where observations are missing. The observed and interpolated values are next smoothed by averaging with the two adjacent values along both the latitude and longitude axes. A truncated Fourier harmonic approximation of the space-smoothed values is next computed. The summation is made over the first three harmonics. The results of the computer analysis program are printed out by the computer in two formats, listing 1) all values for each 1° square in time, for all levels; and 2) all values for each depth level, by month, in geographic order.

The computer analysis gives results at the selected levels—surface, 100, 200, and 300 ft., in Fahrenheit. The values for the selected sample were converted to Centigrade, and temperature values for the metric depths of 10, 25, 50, 75, and 100 meters were interpolated linearly for direct comparison with the means of the 1949–1953 Japanese hydrographic cast data.

4. The Comparison

The mean temperatures of the two samples have been compared both graphically and statistically.

Figures 2-7 present the monthly means of both samples, for all levels, for each area plotted against each other. Also shown are the data from each sample plotted separately to show more clearly the phase and amplitude relationships between the annual cycles at the surface and subsurface levels. For illustration of the time smoothing which occurs when only three harmonics are summed, graphs of the monthly mean values derived from the harmonic analysis of the Hanzawa sample are included. Small arrows indicate the extent of one standard deviation, estimated from the range of the BT observations in a given month at the selected depths according to the method of TIPPETT (1941) (See Table III). Crosses indicate the extent of one standard deviation estimated from the range of temperature for the Hanzawa sample. The Japanese hydrographic cast data included in the Robinson sample were tabulated only as monthly means, with the corresponding numbers of observations. It was, thus, not possible to use these observations to obtain values of the temperature variability in the selected areas.

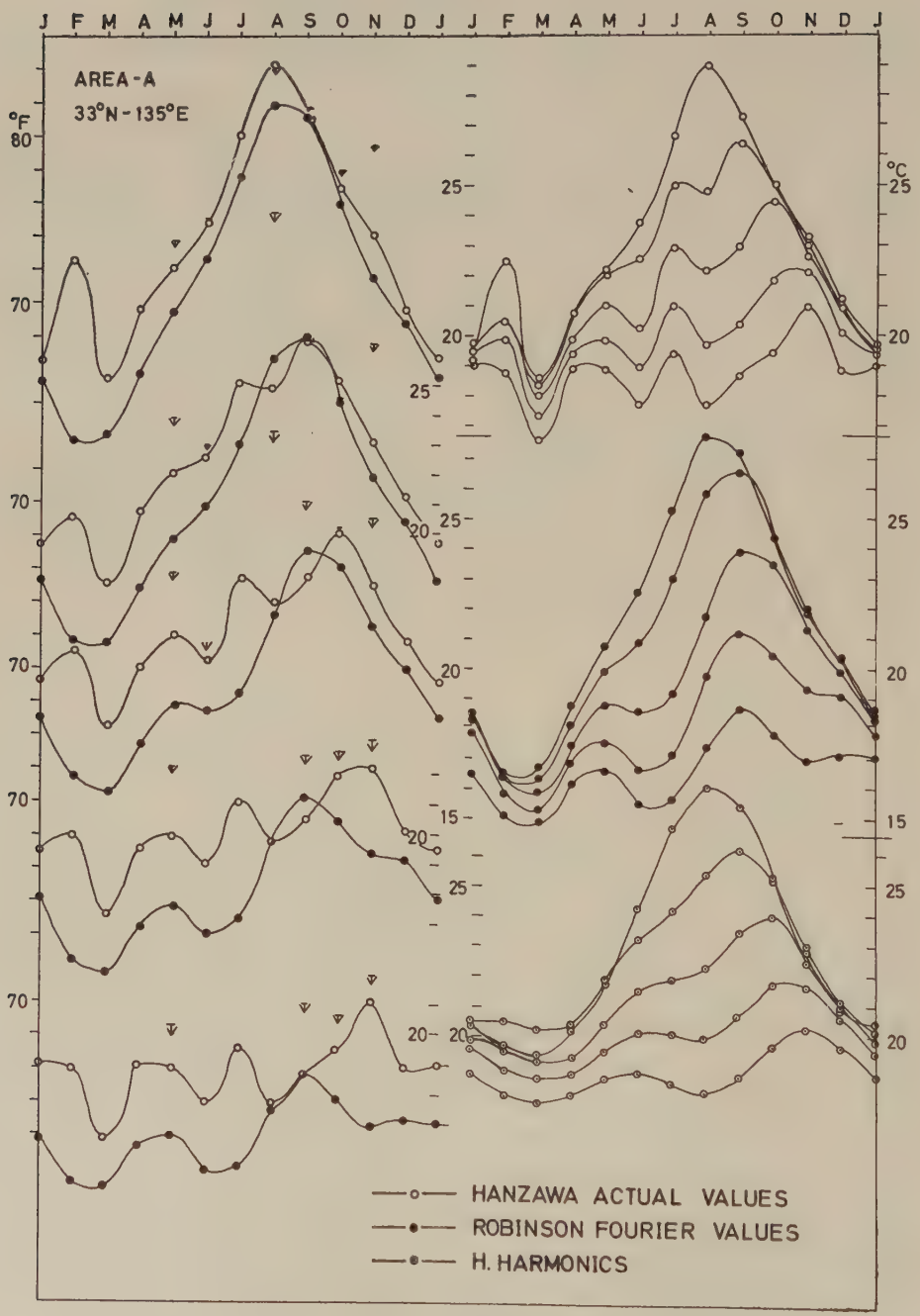

Fig. 2. Monthly means of Hanzawa and Robinson samples for all levels for the Area-A.

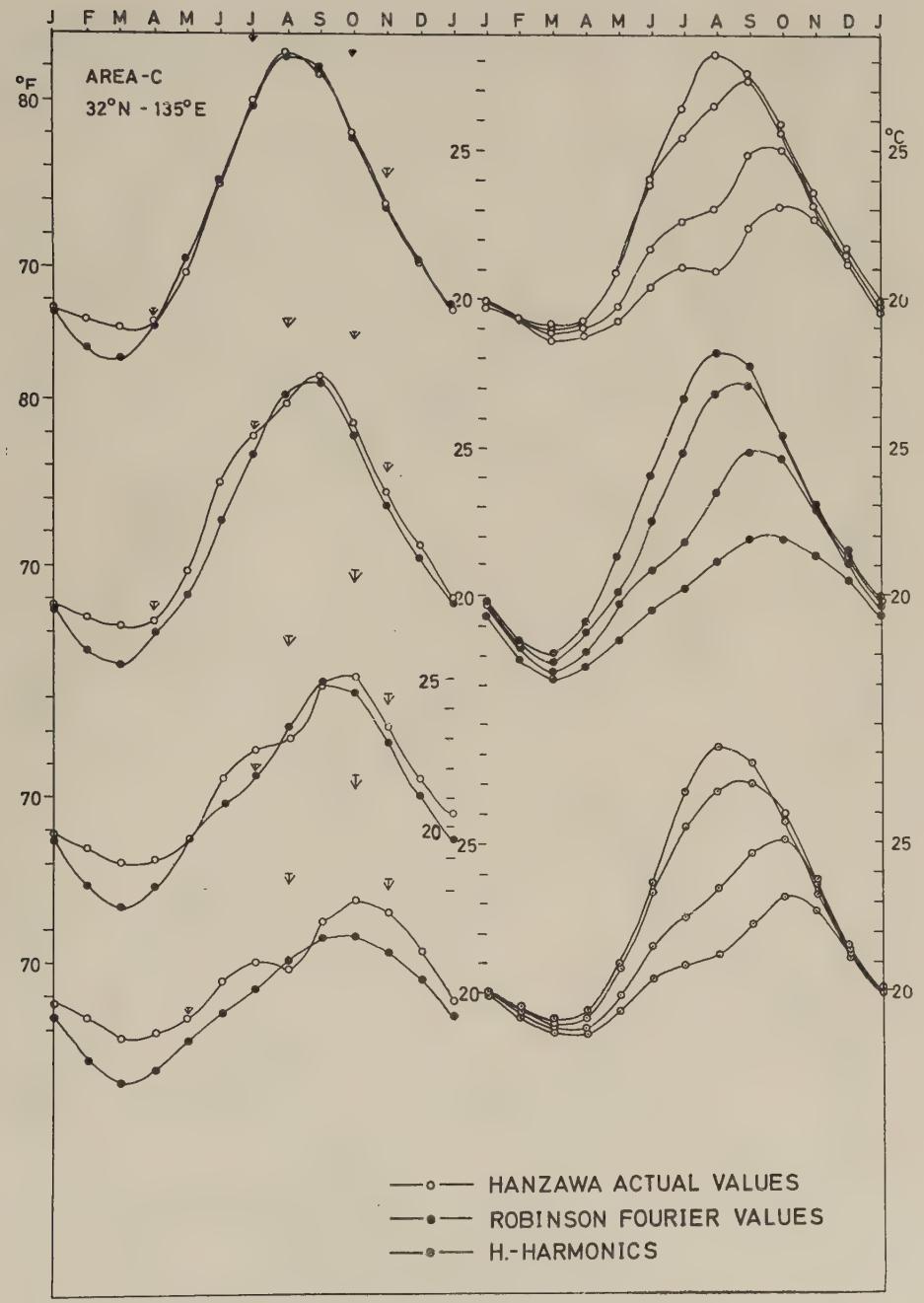

Fig. 3. Monthly means of Hanzawa and Robinson samples for all levels for the Area-C.

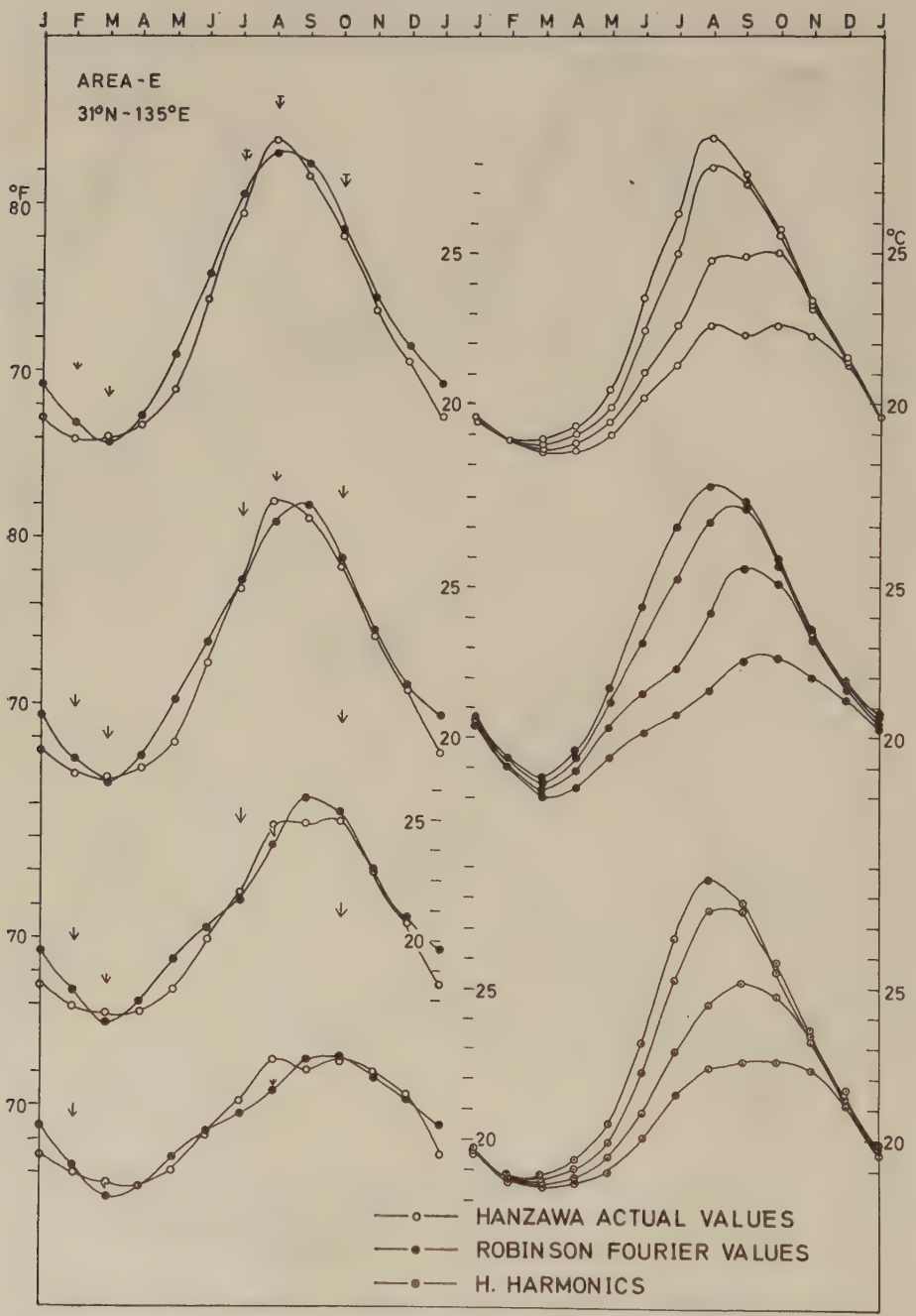

Fig. 4. Monthly means of Hanzawa and Robinson samples for all levels for the Area-E.

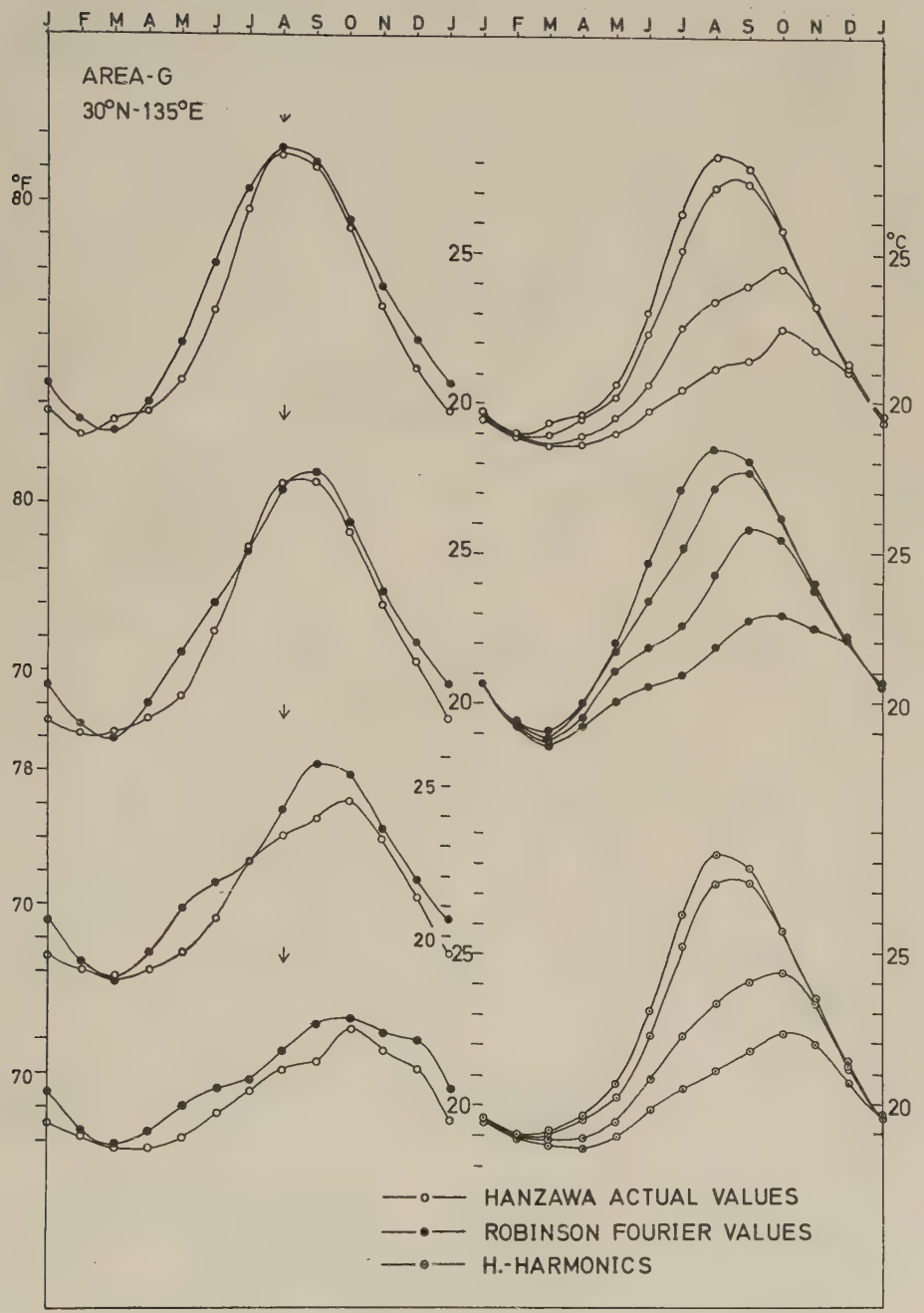

Fig. 5. Monthly means of Hanzawa and Robinson samples for all levels for the Area-G.

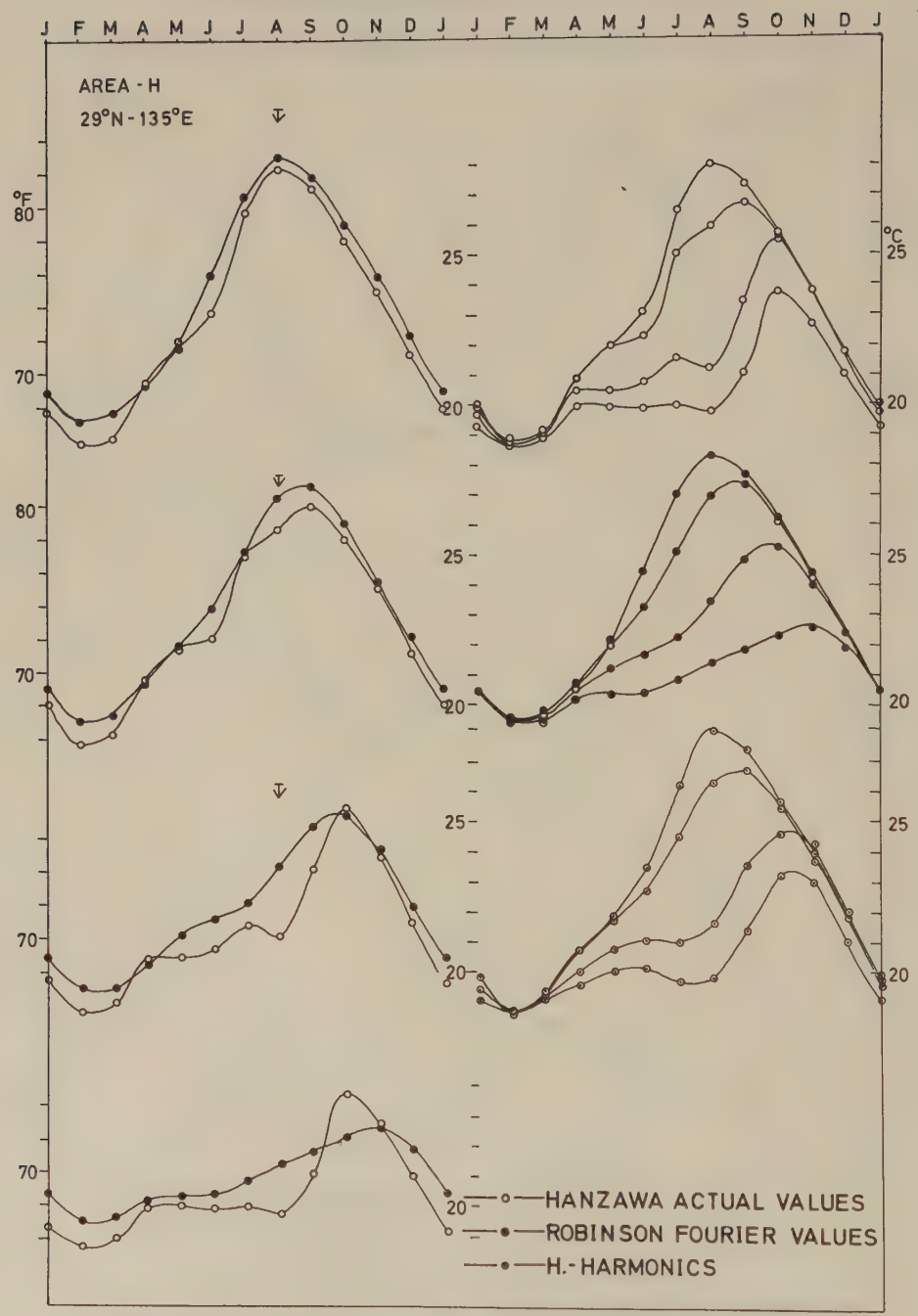

Fig. 6. Monthly means of Hanzawa and Robinson samples for all levels for the Area-H.

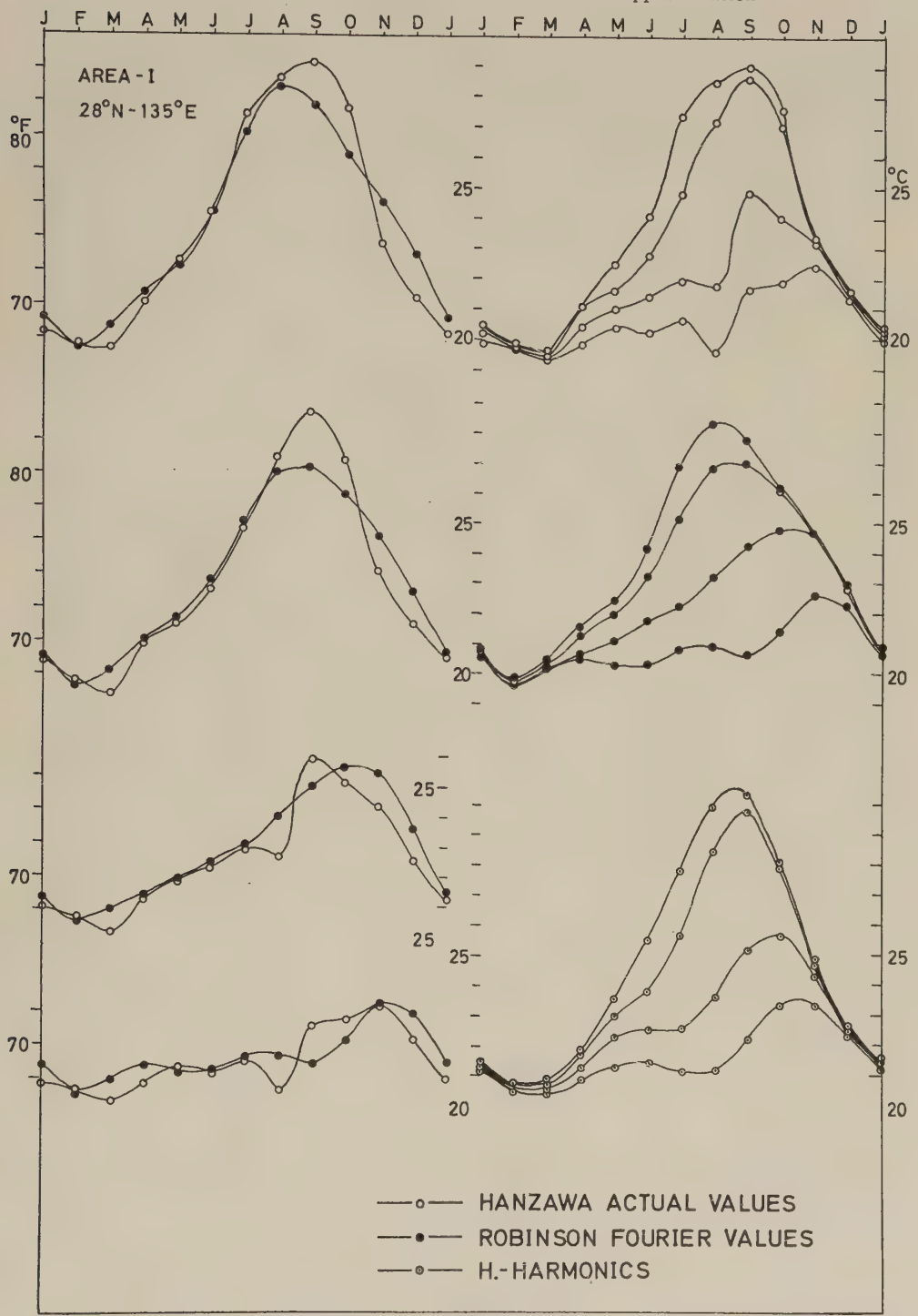

Fig. 7. Monthly means of Hanzawa and Robinson samples for all levels for the Area-I.

TABLE III. Range and Estimated Standard Deviations BT Observations

AREA "A"

Level (Feet)	May R.	Std. Dev.	June R.	Std. Dev.	Aug. R.	Std. Dev.	Sep. R.	Std. Dev.	Oct. R.	Std. Dev.	Nov. R.	Std. Dev.
0	2.78	2.46	2.78	1.35	1.33	1.14	.39	.34	1.22	1.11	4.94	4.38
100	4.44	3.94	4.33	2.10	5.72	4.89	.11	.10	1.17	1.06	4.94	4.38
200	4.89	4.33	4.56	2.21	7.16	6.13	1.89	1.67	1.56	1.38	2.50	2.22
300	5.17	4.58					1.56	1.38	2.61	2.32	4.28	3.79
400	4.11	3.64					2.56	2.27	3.11	2.76	5.67	5.02
N	2		4		3		2		2		2	

AREA "C"

Level (Feet)	Apr. R.	Std. Dev.	July R.	Std. Dev.	Aug. R.	Std. Dev.	Sep. R.	Std. Dev.	Oct. R.	Std. Dev.	Nov. R.	Std. Dev.
0	.55	.49	2.56	2.27	2.44	2.09			3.50	2.99	1.44	1.28
100	1.11	.98	1.11	.98	3.00	2.57			4.11	3.52	1.61	1.43
200	.17	.15	.39	.34	3.61	3.09			4.78	4.09	1.89	1.67
300	1.28	1.13			3.44	2.94			6.39	5.47	2.78	2.46
400	.22	.19			3.22	2.76			6.39	5.47	3.33	2.96
N	2		2		3				3		2	

AREA "E"

Level (Feet)	Feb. R.	Std. Dev.	Mar. R.	Std. Dev.	July R.	Std. Dev.	Aug. R.	Std. Dev.	Oct. R.	Std. Dev.	Nov. R.	Std. Dev.
0	2.22	1.97	2.17	1.92	1.61	1.42	2.11	1.87	2.78	2.38	4.06	3.47
100	2.22	1.97	2.00	1.77	2.89	2.56	1.89	1.67	2.78	2.38	4.06	3.47
200	2.22	1.97	1.72	1.53	3.17	2.80	.72	.64	4.00	3.42	3.94	3.37
300	2.28	2.02	.44	.39			.39	.34	6.00	5.13	4.17	3.57
400			.11	.10					.11	.09	1.61	1.38
N	2		2		2		2		5		3	

AREA "G"

Level (Feet)	Aug. R.	Std. Dev.
0	2.72	1.07
100	6.94	2.74
200	8.78	3.47
300	15.20	6.00
400	9.70	3.83
N	6	

AREA "H"

Level (Feet)	Aug. R.	Std. Dev.
0	1.90	1.67
100	.89	.78
200	3.06	2.71
300		
400		
N	2	

The seasonal curves of the two samples shown in Figures 2-7 are in best agreement in Area E; in poorest agreement in Area A, where the Hanzawa sample has higher temperatures in all months, at all levels. This area is close to the general location of the axis of the Kuroshio Current, where large seasonal

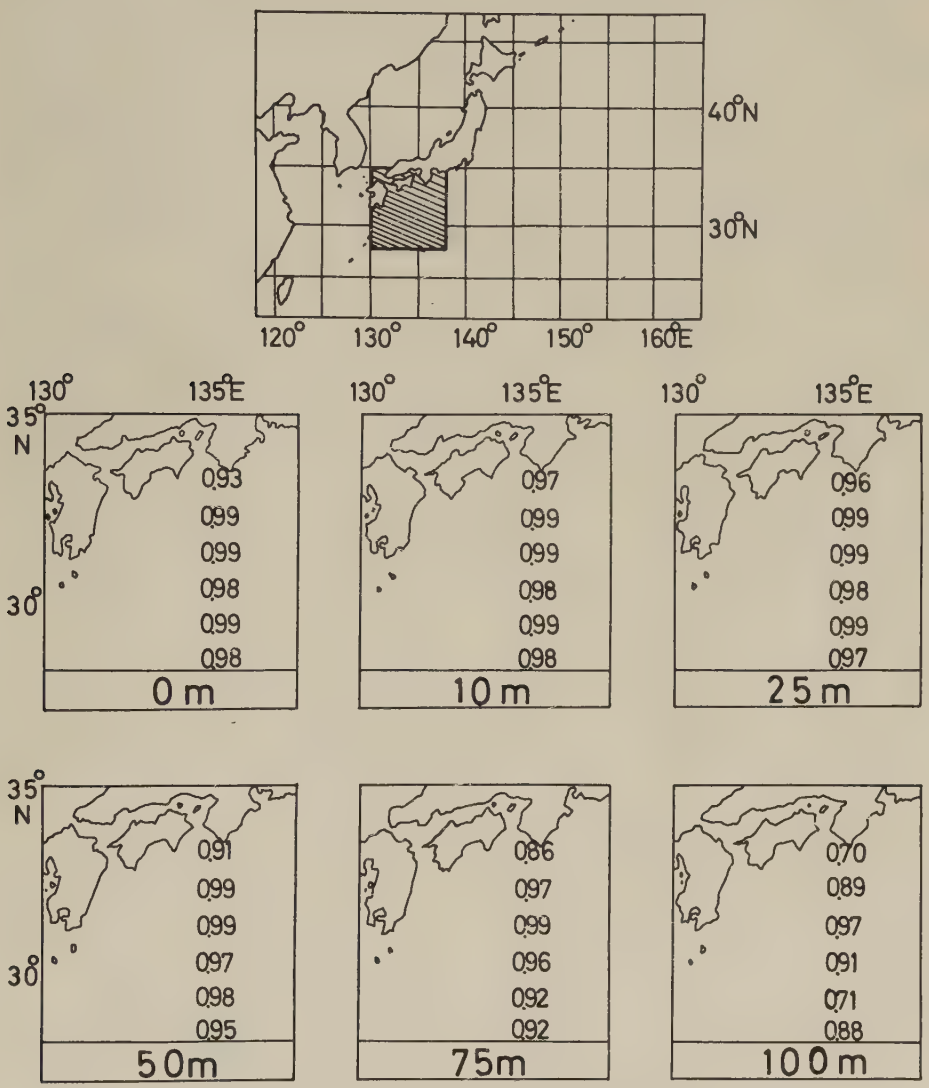

Fig. 8. Correlation coefficients between the Hanzawa hydrocast and Robinson Fourier monthly means, by levels.

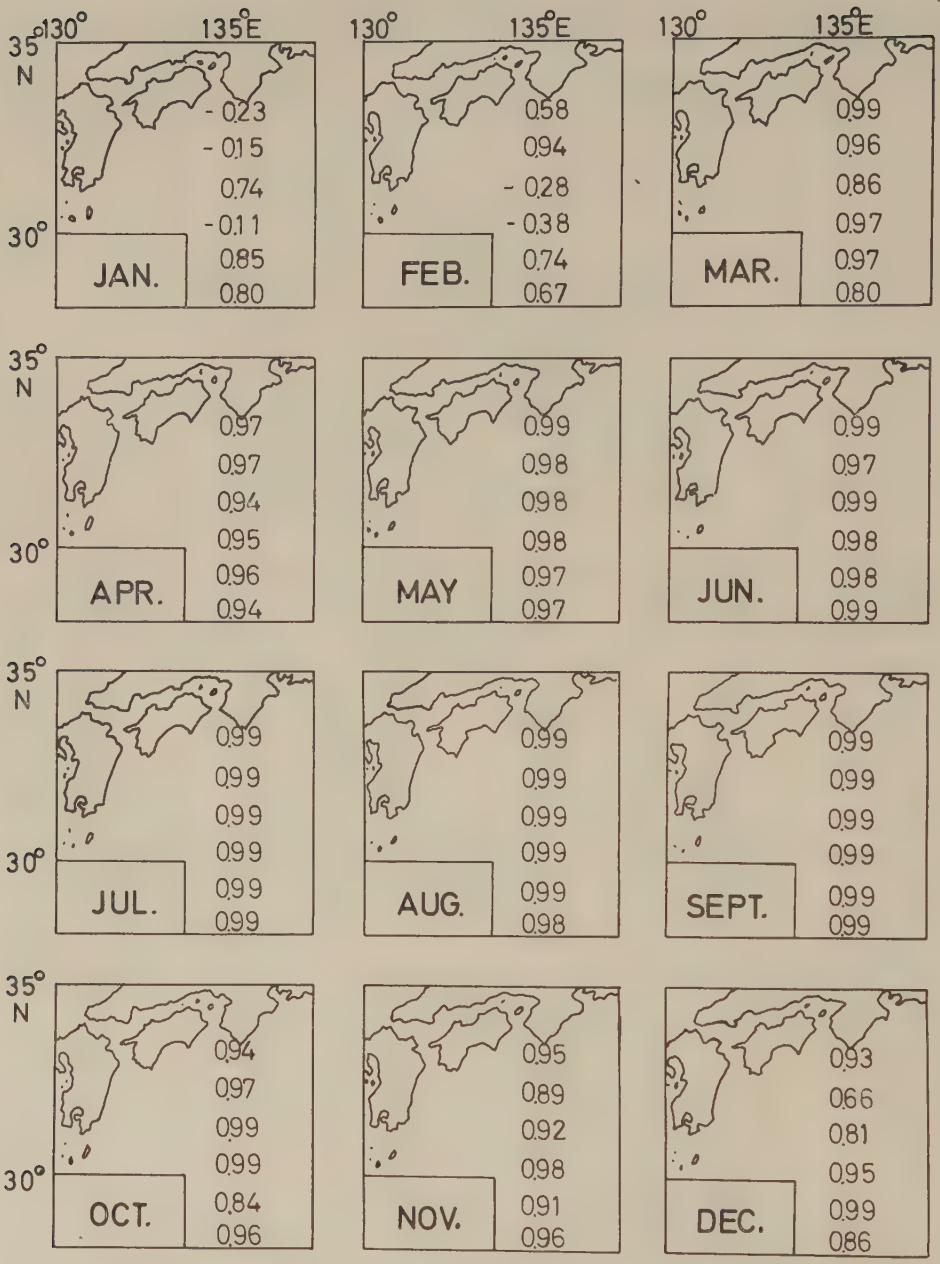

Fig. 9. Correlation coefficients between the Hanzawa hydrocast and Robinson Fourier monthly means, by months.

and year-to-year differences occur. For example, the Hanzawa sample in Area A shows the effects of including a sample value of 22.5°C, which was observed at the surface in February 1952. This is much higher than normal for this month at this location. It must be pointed out, however, that in spite of the magnitude of the differences between the seasonal curves of the two samples, in all areas the means fall within one standard deviation of each other.

In all areas, the annual cycle curves at the surface are dominated by the annual harmonic, although none appear as a simple sine curve. Rather, the summer maximum has a peak of one month's duration, while the winter minimum has a trough lasting at least two months. Beneath the surface, both samples show complex curves containing higher order harmonics. The amplitudes of these higher harmonics appear to be greater in Area A than in the areas to the south. Quantitative comparisons of the harmonic parameters will be discussed below.

The first statistical test was made by computing the correlation between the Hanzawa hydrocast and the Robinson Fourier monthly means, by levels. This computation tests to see if the change of temperature from month-to-month is consistent in both samples. The correlation coefficients were greater than .90 in 32 of the 36 tests. One value at 75 meters, and 3 at 100 meters, fell

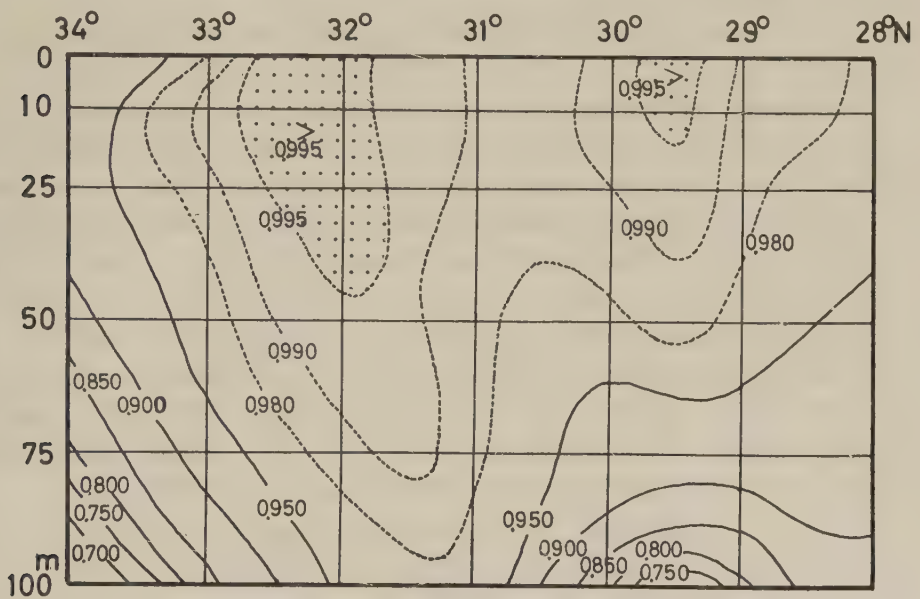

Fig. 10. Vertical cross section of the correlation coefficient along the line perpendicular to the Kuroshio axis.

between .70 and .90. The .01 significance level for these tests, where N=12, is .66. The tests indicate that month-to-month changes are highly correlated for the two sets of data, in all six areas (Fig. 8).

A second test calculated the correlation between monthly means computed over all six depths to see if the temperature change with depth is consistent in the two samples. In 20 of the 36 cases, the coefficients of correlation are greater than .90; in 9 cases, between .70 and .90. The .05 significance level for these tests, where N=6, is .70. In 8 cases, the two sets of data were not significantly correlated—3 cases were in January; 4, in February, and 1, in December. These results indicate that the temperature-depth structure in these areas, in winter, is not always isothermal (Fig. 9).

In Figure 10, a vertical cross section of the correlation coefficient along the line perpendicular to the Kuroshio axis is shown. There are two concentrations of high values; namely, at 32°N, and between 29° and 30°N. The former is in the Kuroshio axis; the latter in a counter-current area, which has been confirmed by both hydrographic and current meter observations. The higher correlations in these two current areas suggest that, although the absolute temperature may be highly variable in current regions, the temperature changes with depth and season are remarkably stable.

Quantitative estimates of the differences in the two samples are shown in Tables IV, V, and VI.

In Table IV, are tabulated the mean differences and the standard deviations of the differences between the two samples. The positive bias of the Hanzawa sample in Area A contrasts sharply with the values in the areas to the south. It is also noteworthy that the mean temperature differences increase with depth in the northern three areas, decrease with depth in the southern three. These differences appear to be related to the high variability in depth of the thermocline in the Kuroshio Region. When the differences are summed over all areas, all levels, the absolute difference is .79°C, and the algebraic difference, .39°C. These low values indicate that the mean temperature for the entire area is approximately the same, and either sample would give a good estimate of the mean seasonal variation at surface and at subsurface levels in this region.

In Table V, are tabulated the standard deviations of the monthly means from annual mean for both samples. These values were derived from the correlation computations. There is remarkably close agreement in the standard deviations of two samples.

TABLE IV. Mean Differences and Standard Deviations of Differences (°C) Between Hanzawa Sample Monthly Means and Robinson Sample

	Depth (Meters)	Mean Differences		Std. Deviations of Differences
		Absolute	Algebraic	
AREA "A"				
33°N, 135°E	0	1.63	1.63	1.47
	10	1.75	1.74	.93
	25	1.76	1.76	.95
	50	1.81	1.81	.99
	75	1.96	1.96	.91
	100	2.00	2.00	.96
AREA "C"				
32°N, 135°E	0	.52	.44	.44
	10	.71	.70	.45
	25	.89	.89	.40
	50	.99	.99	.42
	75	1.21	1.17	.40
	100	1.53	1.53	.63
AREA "E"				
31°N, 135°E	0	.33	−.24	.30
	10	.30	−.16	.29
	25	.30	−.06	.28
	50	.31	.13	.34
	75	.37	.34	.26
	100	.65	.65	.37
AREA "G"				
30°N, 135°E	0	.55	−.42	.44
	10	.52	−.32	.36
	20	.53	−.24	.34
	50	.57	−.42	.34
	75	.60	−.44	.31
	100	.49	−.20	.27
AREA "H"				
29°N, 135°E	0	.76	−.76	.26
	10	.59	−.59	.28
	25	.50	.58	.26
	50	.09	−.56	.37
	75	.79	−.27	.64
	100	.66	−.27	.45
AREA "I"				
28°N, 135°E	0	.58	.27	.46
	10	.55	.30	.51
	25	.63	.35	.51
	50	.49	−.08	.40
	75	.40	−.05	.40
	100	.34	.07	.33
ALL AREAS	0	.73	.15	
	10	.73	.28	
	25	.76	.54	
	50	.71	.31	
	75	.88	.45	
	100	.94	.63	
	All Levels—	.79	.39	

TABLE V. Standard Deviations of Monthly Means From Annual Mean, by Levels

Level (Meters)		AREA					
		A	C	E	G	H	I
0							
	R	3.76	3.71	3.43	3.31	2.96	3.12
	H	3.00	3.29	3.46	3.32	3.06	3.40
10							
	R	3.50	3.58	3.35	3.22	2.84	3.00
	H	2.90	3.21	3.42	3.30	2.98	3.32
25							
	R	3.10	3.30	3.16	3.03	2.65	2.83
	H	2.53	3.10	3.37	3.22	2.83	3.20
50							
	R	2.35	2.64	2.51	2.46	1.89	2.16
	H	1.97	2.45	2.80	2.40	2.07	2.05
75							
	R	1.75	1.96	1.84	1.82	1.18	1.45
	H	1.50	1.80	2.01	1.67	1.94	1.28
100							
	R	1.21	1.37	1.22	1.25	.73	.99
	H	1.18	1.32	1.22	1.40	1.07	.82

TABLE VI. Standard Deviations of Monthly Means of Each Level From Monthly Mean for All Levels

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
AREA "A" (33°N, 135°E)												
R	.38	.88*	.59	.68	1.22	1.96	2.81	3.57	3.03	1.83*	.97	.52
H	.19	.22	.27	.65	.99	1.96	2.24	3.40	2.90	.46	.48	.49
AREA "C" (32°N, 135°E)												
R	.30*	.16	.26	.65*	1.14	1.81	2.56	2.99	2.70	1.84	.96	.51*
H	.09	.07	.25	.21	.70	1.48	2.28	2.95	2.25	1.18	.54	.17
AREA "E" (31°N, 135°E)												
R	.22	.16	.29	.55	.96	1.74	2.64	2.94	2.44	1.59	.93	.49*
H	.03	.02	.10	.32	.57	1.28	2.04	2.56	2.25	1.39	.78	.16
AREA "G" (30°N, 135°E)												
R	.13*	.16	.29	.43	.80	1.52	2.41	2.94	2.72	1.52	.68	.32
H	.09	.07	.28	.41	.67	1.35	2.38	2.82	2.38	1.42	.79	.36
AREA "H" (29°N, 135°E)												
R	.34*	.12	.22	.47	1.00	1.44	2.63	3.77	3.06	2.12	1.02	1.02*
H	.14	.07	.10	.43	.94	1.34	5.70	3.50	2.65	1.20	.79	.44
AREA "I" (28°N, 135°E)												
R	.19	.19*	.21	.69	.84	1.57	2.69	3.78	3.14	2.40	1.73	.20
H	.14	.06	.13	.38	.79	1.52	2.52	3.04	2.71	1.75	.60	.19

* Variance Ratio test indicates significant differences at .05 level.

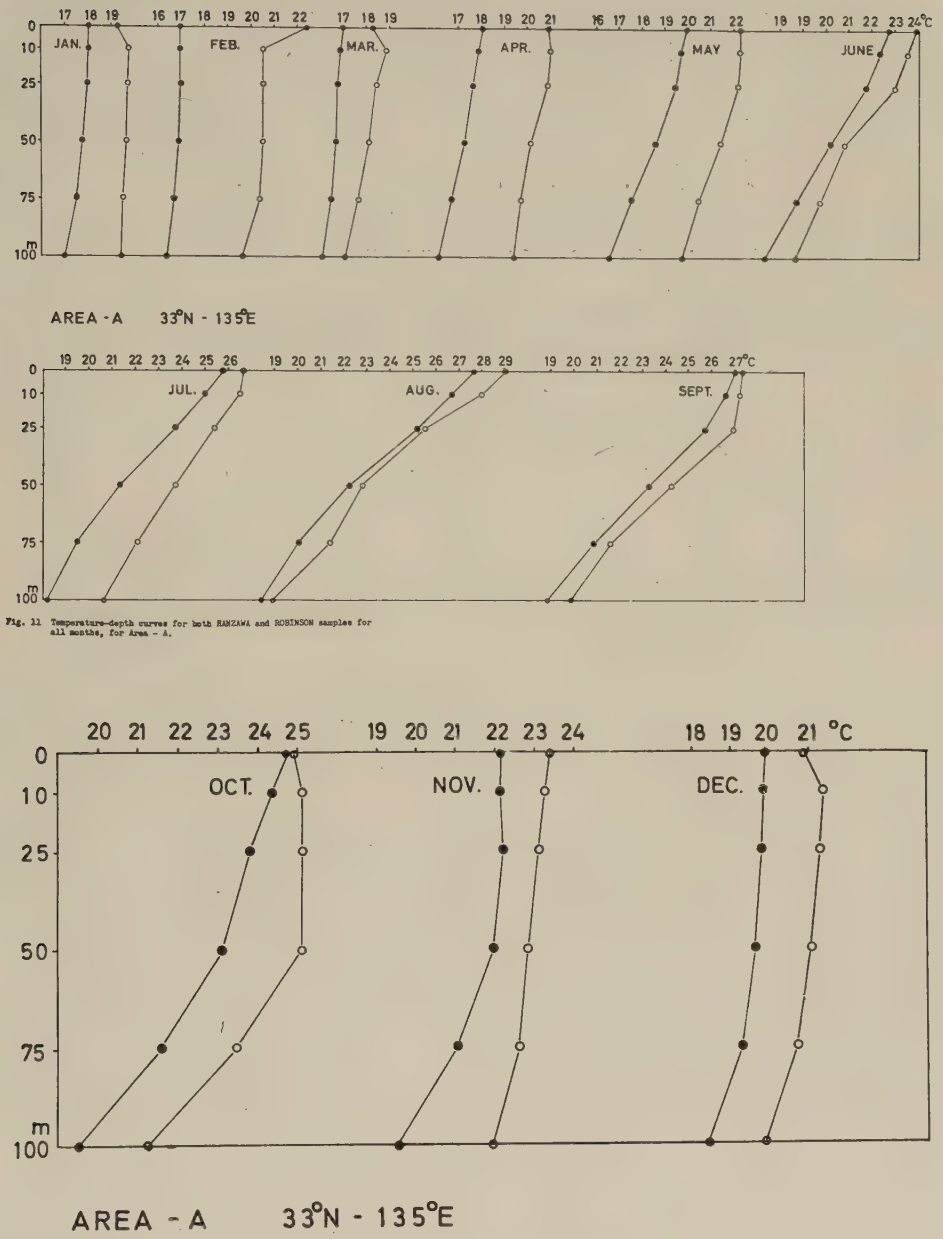

Fig. 11 Temperature-depth curves for both HANZAWA and ROBINSON samples for all months, for Area - A.

Fig. 11. Temperature-depth curves for both Hanzawa and Robinson samples for all months, for Area-A.

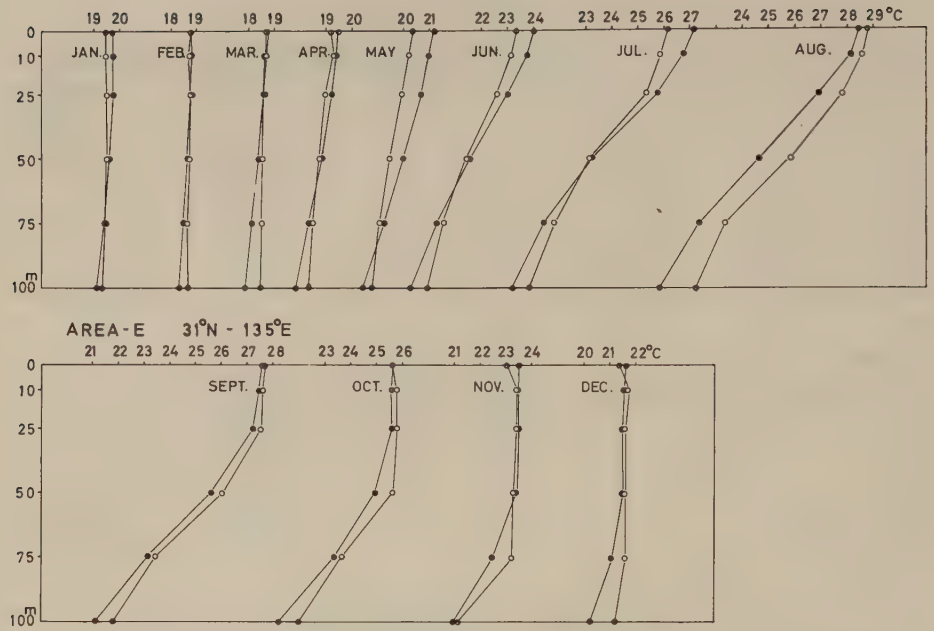

Fig. 12. Temperature-depth curves for both Hanzawa and Robinson samples for all months, for Area-E.

None of the values differ significantly by the Variance Ratio test (Fisher and Yates, 1948). The standard deviations decrease with depth, as expected, because of the decrease in amplitude of the annual cycle. Values in Area H are slightly lower than in the other areas.

In Table VI, are similarly tabulated the standard deviations of monthly means of each level from the monthly mean for all levels. These values, too, were derived from the correlation computations mentioned above. There is good agreement between the standard deviations of the two samples in most summer months. However, there are a number of instances where the Variance Ratio test indicates significant differences in the variance (square of the standard deviations) as indicated in the Table. These cases give some indication of the extent of the differences in temperature-depth structure in winter, which was originally revealed by the non-significant correlation coefficients.

In Figures 11 and 12, temperature-depth curves have been constructed for both Hanzawa and Robinson samples, for all months, for Areas A and E. These graphs show remarkably good agreement in the shape of the temperature-depth curves, and temperature differences from one level to the next, even though the

TABLE VII. Comparison of Harmonic Parameters

	A_0	A_1	A_2	A_3	ϕ_1	ϕ_2	ϕ_3
AREA "A"—33°N, 135°E							
Surface:							
R	21.7	5.1	0.4	0.7	228	24	140
H	23.3	4.0	1.1	0.1	233	21	21
H—R	1.6	−1.1	0.7	−0.6	5	−3	−119
30.5 Meters:							
R	21.0	4.6	0.4	0.7	219	316	128
H	23.1	4.0	0.6	0.2	225	308	53
H—R	2.1	−0.6	0.2	−0.5	6	−8	−75
61 Meters:							
R	19.5	3.3	0.8	0.8	201	262	102
H	22.7	3.5	0.3	0.4	207	1	207
H—R	3.2	0.2	−0.5	−0.4	6	99	105
90.5 Meters:							
R	18.1	2.3	0.6	0.9	190	262	121
H	21.7	2.6	0.4	0.4	187	202	333
H—R	3.6	0.2	−0.2	−0.5	−3	−60	−148
Mean Difference:							
Algebraic	2.6	−0.3	0.05	−0.5			
Absolute					5	43	112
AREA "C"—32°N, 135°E							
Surface:							
R	22.7	4.9	0.6	0.2	228	51	126
H	22.9	4.6	0.8	0.1	226	27	276
H—R	0.2	−0.3	0.2	−0.1	−2	−24	150
30.5 Meters:							
R	22.2	4.4	0.3	0.3	220	12	102
H	23.0	4.5	0.7	0.1	220	15	346
H—R	0.8	0.1	0.4	−0.2	0	3	−116
61 Meters:							
R	21.0	3.4	0.3	0.4	205	262	60
H	22.8	4.3	0.6	0.2	203	267	348
H—R	1.8	0.9	0.3	−0.2	−2	5	−72
90.5 Meters:							
R	19.7	2.3	0.2	0.2	195	182	85
H	22.0	3.4	0.3	0.5	190	214	336
H—R	2.3	1.1	0.1	0.3	−5	32	−109
Mean Difference:							
Algebraic	1.3	0.5	0.2	−0.05			
Absolute					2	16	112

TABLE VII. Comparison of Harmonic Parameters (Continued)

	A_0	A_1	A_2	A_3	ϕ_1	ϕ_2	ϕ_3
AREA "E"—31°N, 135°E							
Surface:							
R	23.3	4.6	0.7	0.2	226	53	106
H	22.8	4.8	0.9	0.3	225	24	203
H—R	−0.5	0.2	0.2	0.1	−1	−29	97
30.5 Meters:							
R	22.8	4.2	0.4	0.4	219	20	90
H	22.7	4.7	0.8	0.3	217	7	194
H—R	−0.1	0.5	0.4	−0.1	−2	−13	104
61 Meters:							
R	21.8	3.2	0.3	0.5	204	287	65
H	22.5	4.6	0.8	0.3	206	316	255
H—R	0.7	1.4	0.5	−0.2	2	29	−170
90.5 Meters:							
R	20.9	2.1	0.2	0.3	191	168	235
H	21.9	3.9	0.5	0.0	199	158	165
H—R	1.3	1.8	0.3	−0.3	8	−10	−70
Mean Difference:							
Algebraic	0.4	1.0	0.4	−0.1			
Absolute					3	20	110
AREA "G"—30°N, 135°E							
Surface:							
R	23.4	4.6	0.5	0.1	227	51	134
H	22.8	4.6	0.9	0.2	225	7	206
H—R	−0.6	0.0	0.4	0.1	−2	−44	72
30.5 Meters:							
R	23.0	4.1	0.3	0.4	220	352	100
H	22.8	4.6	0.9	0.3	220	354	207
H—R	−0.2	0.5	0.6	−0.1	0	2	107
61 Meters:							
R	22.0	3.1	0.4	0.4	206	263	73
H	22.7	4.4	0.9	0.2	204	277	292
H—R	0.7	1.3	0.5	−0.2	−2	14	−141
90.5 Meters:							
R	20.9	1.9	0.3	0.2	193	208	88
H	21.7	3.4	0.4	0.2	192	238	307
H—R	0.8	1.5	0.1	0.0	−1	30	−141
Mean Difference:							
Algebraic	0.2	0.8	0.4	−0.05			
Absolute					1	23	115

TABLE VII. Comparison of Harmonic Parameters (Continued)

	A_0	A_1	A_2	A_3	ϕ_1	ϕ_2	ϕ_3
AREA "H"—29°N, 135°E							
Surface:							
R	23.5	4.2	0.3	0.3	227	303	211
H	23.1	4.3	0.3	0.5	228	353	184
H—R	−0.4	0.1	0.0	0.2	1	50	−27
30.5 Meters:							
R	23.1	3.8	0.4	0.2	220	311	142
H	23.1	4.2	0.3	0.5	221	280	164
H—R	0.0	0.4	−0.1	0.3	1	−31	22
61 Meters:							
R	22.1	2.6	0.7	0.2	203	248	62
H	22.9	4.0	0.4	0.5	195	240	334
H—R	0.8	1.4	−0.3	0.3	−8	−8	−88
90.5 Meters:							
R	20.9	1.3	0.5	0.2	186	214	202
H	21.7	2.7	1.1	0.1	183	233	322
H—R	0.8	1.4	0.6	−0.1	−3	19	120
Mean Difference:							
Algebraic	0.3	0.8	0.05	0.2			
Absolute					3	27	64
AREA "I"—28°N, 135°E							
Surface:							
R	23.8	3.9	0.3	0.5	227	2	203
H	23.7	4.7	0.9	0.2	229	343	78
H—R	−0.1	0.8	0.6	−0.3	2	−19	−125
30.5 Meters:							
R	23.2	3.4	0.4	0.3	219	294	192
H	23.6	4.6	0.9	0.3	220	323	93
H—R	0.4	1.2	0.5	0.0	1	29	−99
61 Meters:							
R	22.0	2.1	0.8	0.3	195	231	283
H	23.4	4.3	1.1	0.5	203	254	45
H—R	1.4	2.2	0.3	0.2	8	23	122
90.5 Meters:							
R	20.8	0.8	0.6	0.5	165	190	222
H	22.2	2.7	0.8	0.5	178	219	345
H—R	1.4	1.9	0.2	0.0	13	29	123
Mean Difference:							
Algebraic	0.8	1.5	0.4	−0.02			
Absolute					6	25	117

absolute temperatures, particularly in Area A, are quite different.

The Hanzawa hydrographic cast data were subjected to the truncated Fourier harmonic analysis to obtain a comparison of the harmonic parameters derived from each set of data. The comparison of the harmonic parameters are presented in Table VII. The difference in amplitude of A_0 (annual mean) is largest in Area A, primarily because of the large difference in the winter temperatures (Fig. 2); however, there are surprisingly large differences in A_0 at 61 and 90.5 meters in Areas C, E, and I. These probably reflect real year-to-year difference in heat content in these areas between the two samples. The differences in A_1 and A_2 are, in general, small. There is very good agreement in the phase angles of the annual constituents. The phase difference between the semi-annual constituents of the two samples when converted to days averages approximately 12 days; the phase difference for the ter-annual constituents, approximately 35 days. The amplitude and phase of the second and third harmonics are such that one should not except that the precise seasonal curves of the Robinson model will be reproduced on an annual basis; however, harmonics of this order of magnitude may be expected beneath the surface at all times in these areas.

Robinson (1954, 1975) pointed out the existence of a double cycle in low latitude areas of the Western Pacific, and in the Gulf of Alaska. Her explanation of this phenomena, given by personal communication, is as follows:

In spring, in northern latitudes, as the surface temperature increases, there is usually a slight increase of temperature in the whole water column above the permanent thermocline, with heat being transmitted to the lower levels both by mixing and advection. The seasonal thermocline is well developed by June, and the stability in the thermocline layers increases to such an extent that the transfer of heat across the layer is materially impeded. Temperature beneath the thermocline in these months is primarily dependent upon advection, or mixing with colder water below, and may increase or decrease depending upon local conditions. In fall, when the surface temperature begins to cool, convection cells are set up, the thermocline deepens, and although temperature is decreasing in the layer above the thermocline, the deepening of the layer brings higher temperature to increasing depths. Thus, there is a lag in the time of maximum temperature at successive depths.

A quantitative description of this process has not yet been given. The problem merits attention because it is not only the sea surface temperature which is important in air-sea interaction problems, but the distribution of heat

within the entire surface layer.

A further check of both samples was made by computing the correlation between these data and Japanese Marine Climatological data for the surface only. The Japanese tables are arranged for 2° latitude by 5° longitude squares, and the closest counterpart squares were chosen for comparison. Correlations greater than .93 were obtained for all areas, indicating highly significant correlations for month-to-month temperature changes in both comparisons.

5. *Conclusion*

(a) The temperature-depth models derived by the Fourier approximation of space-interpolated and smoothed temperature data were verified by comparison with detailed serial hydrographic cast data.

(b) High correlation coefficients are found between the Fourier values and the hydrocast data in the Kuroshio axis and in the counter-current area.

(c) Differences between the two samples were examined statistically and graphically. Absolute temperature differences were found, but differences did not exceed limits of variance in the region.

(d) Existence of the so-called double cycles in the trend of subsurface temperatures is confirmed in these waters.

(e) The differences between the Hanzawa and Robinson samples appear to be within the limits of the known variability of temperature in the upper 100 meters in these areas perpendicular to the Kuroshio. The Robinson model is derived from data covering a longer time span and it may, therefore, be more representative of average conditions.

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印刷者　花崎実
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